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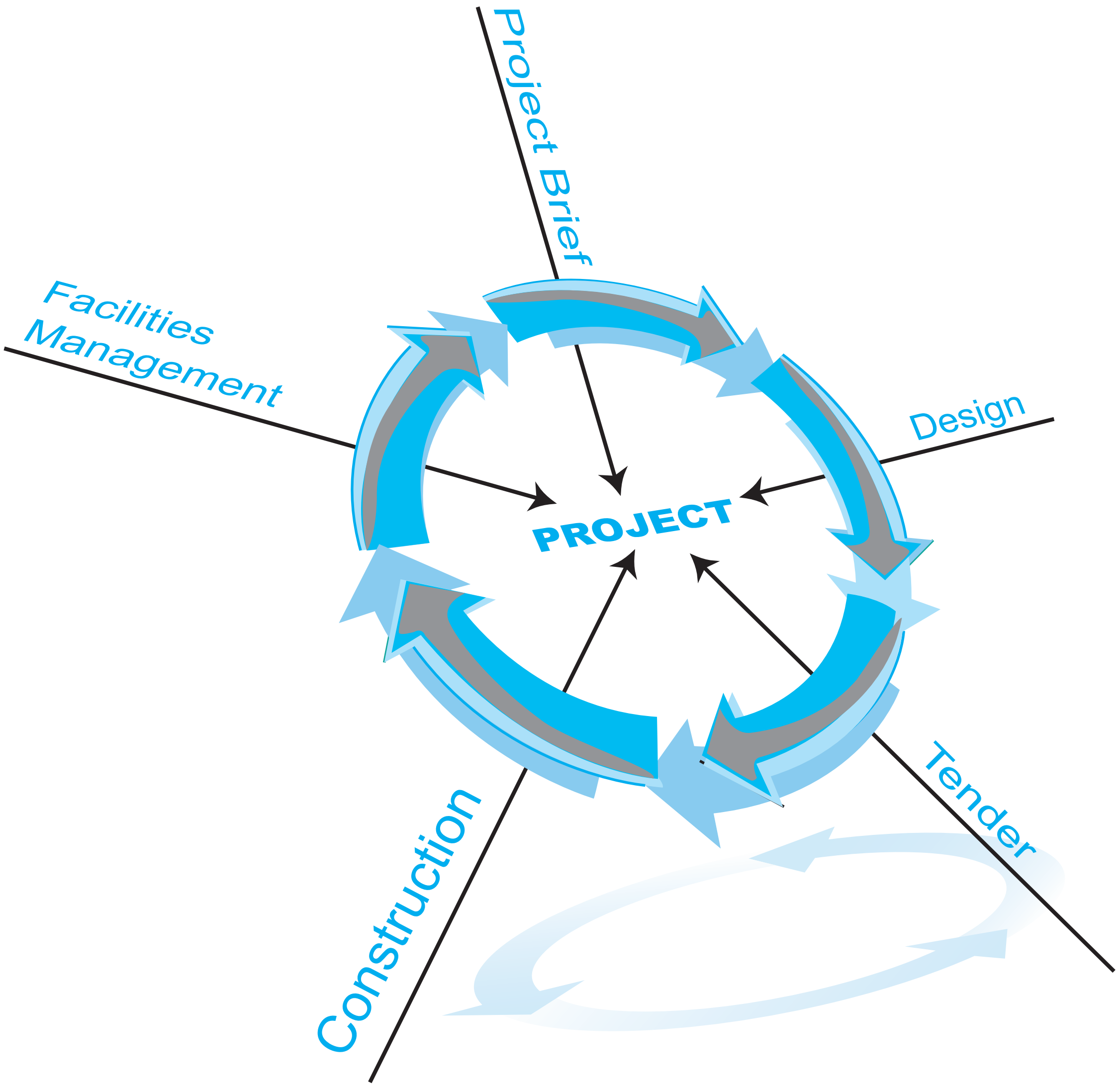

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Contents

Editorial Advisory Board

Editorial

Welcome from the Editors

Welcome to the ninth issue of Malaysian Construction Research Journal (MCRJ). The editorial team would like to extend our gratitude to all authors and reviewers for their continuous contributions and valuable comments. It is hope that the readers will find beneficial information from this edition of MCRJ. 6 papers are discussed in this issue.

Mohd Nasrun Mohd Nawi, et. al. review the concept of team integration in Industrialised Building System (IBS) project. In this paper, the concepts of team, teamwork and integration within scope of construction project is reviewed and defined. The main dimensions that describe a team that has been fully integrated, followed by discussion on how the delivery team a responsible for the design and construction of a project can be integrated to work together is also discussed.

Mohamed Nor Azhari Azman, et. al. study on the trend of the use of IBS components and identifies the factors required for the setting up of IBS manufacturing factories in the Malaysian construction industry. A pilot study was conducted with seven interviews with manufacturing players, academician and government agency. The findings of the study are discussed in this paper.

Akinola Johnson Olarewaju et.al. report the behavior of buried pipes due to the internal explosion. Among the parameters studied are the materials and dimensions of pipes, blast energies, soil properties and the depth of burial. The behavior of pipes is determined using finite element modeling and is discussed further in this paper.

Chee Siang Chong et.al. discuss the findings of the research which focuses on the optimization of concrete mix design using sandstone reactive aggregate. The presence of reactive aggregates, high alkaline pore solution and high moisture level in concrete are the main sources of Alkali Silica Reaction (ASR) which may contribute to concrete cracks. The research develops the optimum concrete mix design to reduce the ASR of the sandstone aggregate quarries located in Sabah.

Ng Chee Hiong, et.al. explore the potential of using renewable resources as alternative to construction materials. A by product of the agricultural sector, the Oil Palm Shell (OPS) is used as coarse aggregates in concrete production known as OPS concrete and has been recommended as structural lightweight concrete. This paper discusses the behaviour of precast C-channel floor of various span subjected to uniformly distributed loading. Laboratory works have proved that the C-channels can be fabricated using OPS hybrid concrete with minimum compressive strength of 22 MPa.

Malik M A Khalfan et.al. investigate the relationship among supply chain participants in different methods of project procurement. Primary and secondary data collections are used in order to establish the extent of supply chain relationship and integration within Victorian construction organizations.

Editorial Committee

A CRITICAL LITERATURE REVIEW ON THE CONCEPT OF TEAM INTEGRATION IN INDUSTRIALISED BUILDING SYSTEM (IBS) PROJECT

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Abstract

Due to the combination of problems and issues that arose in the current construction industry such as fragmentation, less of productivity and quality, lack of sustainability etc, the Malaysian Government proposed a new solution through industrialisation technology called Industrialised Building System (IBS). Although IBS was introduced over 40 years ago, with well-documented benefits and strong support from the government, the pace of implementation and usage of IBS is still slow and below the government targets. Investigation by some researchers identified that one of the main barriers of IBS implementation in the Malaysian construction industry is related to poor integration and communication among stakeholders involved during the design stage. A number of reports challenged the construction industry to create a fully integrated process capable of delivering predictable results to clients through processes and team integration. Responding to the challenge, this research hopes to respond this problem and help towards the betterment of the IBS Malaysian construction industry using an integrated design team delivery approach. Therefore, this paper will review and define the concepts of team, teamwork and integration within scope of construction project. In the second part, this paper will discuss the main dimensions that describe a team that has been fully integrated, followed by discussion on how the delivery team a responsible for the design and construction of a project can be integrated to work together.

Keywords: *Industrialised Building System (IBS), Integration, Integrated Practice, Critical Success Factor (CSFs)*

INTRODUCTION

The importance of the construction industry to national social-economies is no subject for debate. Its contribution to Gross Domestic Product (GDP), impact on economic activity, government revenue, benefits of investment and employment is significant (UKCG Report, 2009). For example, as a developing country, Malaysia is rapidly developing in every domain including construction. The construction sector is one of the main pillars of Malaysia domestic economy. The industry growth was at 5.3% and contributed a 2.1% total to the GDP in 2009 (CIDB, 2010) and it provides job opportunities for 800,000 people which are 8% of the total workforce (CIMP, 2005). The conventional method of construction which is widely practiced in Malaysia is labour intensive, involving formwork fabrication, steel bending and concreting. It requires many wet trades on site such as skilled carpenters, plasterers and brick workers and can be hampered by quality issues and skills shortages (Hamid et al. 2007). Numerous researchers (Egan, 2002; Egan, 1998; Fairclough, 2002; Latham, 1994) highlighted that improved project sustainability is required if the industry is to attract more work and investments. This finding supports existing literature which states that improved components, materials and construction methods, including standardization and pre-assembly is important factors towards sustainable project in construction industry (Nawi et al. 2009; Egan, 1998).

RESEARCH METHOD

This paper is a preliminary study to an ongoing PhD research on IBS implementation and still at the initial stage; therefore, the information presented in this paper is primarily based on the thorough review of the relevant literature within the scope of IBS and construction fragmentation. Wisconsin (2008) identified that a literature review is a "critical analysis of a segment of a published body of knowledge through summary, classification, and comparison of prior research studies, reviews of literature, and theoretical articles." A literature review seeks to describe, summarise, evaluate, clarify or integrate the content of information. Completing a literature review is usually a significant intellectual achievement in its own right, requiring the analysis and synthesis of previous work in such a manner that new understandings of that work are uncovered, and is opened for new research. Through the literature review, the definition, application, and related issues of IBS and team integration in the construction industry is examined and highlighted. At the same time, numerous tools and strategies developed to improve process and team integration in the traditional practice and its applicability for IBS will be discussed as well. All the data and information gathered directly from libraries, books, articles and other printed materials searched in the international and national journals, proceeding and bulletin. The results are not meant to be conclusive but rather a call for debate and a platform to gather feedback from construction fraternity on the topic. More evidences need to be established to support this paper and pilot study should be conducted to validate points and suggestions which have been highlighted. The authors are hoping that this paper will provide strong foundation for future research and as a preparation to write a comprehensive literature reviews.

OVERVIEW OF MALAYSIAN IBS CONSTRUCTION INDUSTRY

In an attempt to develop a sustainable development in construction process, the Malaysian government has taken the initiative in implementing a new or modern construction method called Industrialized Building System (IBS). IBS (known as offsite manufacturing in UK construction industry) is a construction technique in which components are manufactured in mass production under a controlled environment (on or off site), transported, positioned and assembled into a structure with minimal additional site works (CIDB, 2003). Similarly, Hassim et al. (2009) stated that this industrialization process is essentially an organizational process-continuity of production implying a steady flow of demand; standardization; integration of the different stages of the whole production process; a high degree of organization of work; mechanization to place human labor wherever possible; research and organized experimentation integrated with production. The benefits of IBS are numerous and far reaching. The benefits which could be gained from the implementation of this system help to speed up the construction process, decreasing cost, labor and wastages on site, and minimizing the effect of risk (Hassim, 2009; Kamar et al. 2009; Nawi et al. 2007; Thanoon et al. 2003 and IBS roadmap, 2003).

Although IBS has been introduced for over 40 years, with well-documented benefits and strong support from the government, the pace of implementation and usage of IBS is still slow and below the government target. While many members of the industry are open to the idea, a major portion of the industry stakeholders are indifferent, perhaps due to resistance towards change, or insufficient information regarding the feasibility of change to IBS. Investigation by some researchers identified that one of the main barriers of IBS implementation in the Malaysian construction industry is related to poor integration and communication among stakeholders involved during the design stage (Kamar et al. 2009; Chung, 2006; Haron et al. 2005; and Thanoon et al. 2003). At present, common practice shows that manufacture of IBS components is involved only after the tender stage of the value chain. This lack of integration among relevant players in the design stage has resulted in a need for redesign and additional costs to be incurred if IBS is adopted (Hussein, 2007 and Hamid et al. 2008). There is a desperate need of a new approach of procurement using strategic partnering in the construction delivery system.

This barrier relates to the problem of fragmentation that has been well criticized by previous authors thus contributed to the issues of delays, increased lead times, increased costs and late supply of materials (Blacud et al. 2009; Abadi, 2005; Masterman, 2002; Love and Sohal, 2002; Dainty et al. 2001; Kamara et al. 2000; Ofori, 2000; Egan, 1998; and Anumba et al. 1997).

Notably, these problems are similar to those associated with the traditional construction process (conventional methods) with which IBS is based upon; for example, rework, increasing costs and longer construction duration (Love et al. 2004; Evbuomwan and Anumba, 1998). Therefore, it could be proposed that learning from the improvements made to address the practice of traditional construction process could invariably solve the problems related to the lack of integration in IBS projects. Accordingly, such framework, tools or strategies used to form or enhance integration teams (especially for design and construction process) in the traditional construction process could be borrowed and applied to improve processes and team integration in IBS projects. As highlighted by CIDB (2009), improving procurement systems and supply chains is the key to achieving IBS success in the Malaysian construction industry. Therefore changes in the overall process are required. There is a consensus of opinion that IBS is best handled as a holistic process and requires a total integration of construction, manufacturing and design.

REVIEWS OF CURRENT PROJECT DELIVERY PERFORMANCE

Construction industry is well-known as complex, with its very essence, based on one-off projects and temporary relationships (Smith, 2004). This situation will significantly affect the flow of communication and coordination process among team's members thus contributes to adversarial relationship. For example, the current industry structure has much potential point for conflicts when each participant tries to pass on the risk to others within the work (Cox and Townsend, 1997). It is clearly present in the diversification of the goals of the designers and builder, whereas "the designer wants a functional design that reflects his philosophy and the builder wants a buildable product within reasonable risk limitations" (Mendelsohn, 1998). It clearly shows that 'conflicts, inconsistencies and mismatches' between all of project team members which is possibly due to simple misunderstandings or assumptions problem is mainly caused by the current construction traditional practice (Hegazy et al. 2001; Gardiner and Simmons, 1998).

Previous research had continuously addressed the problems related to fragmentation within the construction industry which has separated design from construction (Latham, 1994; Egan, 1998; Egan, 2002). This poor performance had been blamed on the adversarial relationships between parties in the construction process. The reports advocated for the replacement of adversarial relationships within the construction with cooperation. This has resulted in calls for the integration of the entire supply chain to improve buildability and reduce waste (Bourn, 2001). Further report by Egan (2002) also called for integration of the supply process, respect for people, culture of continuous improvement through performance measurement and investment in research and innovation.

This paper will attempt to focus on identifying the overall concept of integration, which is include its definition, dimensions and current practice of frameworks for achieving fully integrated practice. The critical success factors (CSFs) for integrated project team that responsible for the design and construction of a project will also be discussed in order to improve team integration in IBS Malaysian construction industry. The following sub-section addresses the definition related to team integration as found in current literatures and the key definition within the context of this paper.

DEFINITION OF TEAM, TEAMWORK AND INTEGRATION

In the literature many authors continually refer to teams as groups and groups as teams, neither perceiving nor implying any distinctions between them (Fisher et al. 1997). The distinction between the both terms are often unclear, although the terms 'team' and 'group' have been used to describe rather different entities (Brannick and Prince, 1997). Hayes (2002) argues that even both of the terms share some common characteristics such as membership, norms and cohesion, however they are fundamentally different.

In a 'group,' members tend to be responsible and accountable for their own performance (Brannick and Prince, 1997; Katzenbach and Smith, 1993). Purposely, a group was created in general and in line with organization. Baiden (2006) clearly defines a group as a collection of individually skilled people put together for a purpose and members share information to reinforce individual performance towards achieving their goals and thus their performance is usually a function of what its individual members achieve. The group then develops into a 'team' when it is tasked with a specific and clear purpose and a common goal (Baiden, 2006; Kezsbom, 1990).

In general, such authors suggest that a team is simply a group, but with something extra. For example, a team is defined as a collection of individuals who are interdependent in their tasks (Parker, 1990) who share responsibility for outcomes (Sundstrom et al. 1990), who see themselves and who are seen by others as an intact social entity embedded in one or more larger social systems (for example, business unit or the corporation), and who manage their relationships across organizational boundaries (Cohen and Bailey's, 1997).

Bringing people together however does not necessarily ensure that they will function well as a team (Baiden, 2006). Therefore, it must be a synergetic process in which the efforts of the team members surpass individual efforts (Scarnati, 2001) which means team members need to work with each other (inter-dependence) to succeed (Wilson and Pirrie, 2000). Those behaviors of members that engender information sharing, co-operative efforts by individuals working together and coordination of activities within the team are collectively called 'teamwork' (Baiden, 2006; Dickinson and McIntyre, 1997).

According to Nesan and Holt (1999), teamwork is one of the most widely recommended tools to improve quality of interface problem resolution and decision-making process in an organization. It is because teamwork enables effective tackling of complex problems by a pool of expertise, knowledge, skills and experience through the playing of multiple roles and leadership (Baiden, 2006; Harris and Harris, 1996; Ingram et al. 1997). Towards a successful teamwork in an organization however, it must be supported by major culture changes, organization structure and a working system as well.

The term 'integration' is always being used and has evolved over time in order to describe groups, teams, and teamwork in the construction industry practice. In the construction industry, the word 'integration' has been widely used to describe the concept of freely exchanging information between different participants in the construction process through actual examples have been limited and localized (Vincent and Kirkpatrick, 1995). Previous researchers identified integration in difference ways. Howell (1996) and Jafaari & Manivong (1999) identified integration as the merging of different disciplines with different goals, needs and culture in order to undertake a single task. It is an alignment of various processes to conformity with each other (Dainty et al. 2001). Other researchers identified integration as collaborative working and process for improving team culture and attitude among professionals disciplines (Austin et al. 2002), working in coherent manner (Moore and Dainty, 1999) and management of project activities in comprehensive, collaborative, structured and concurrent style (Love et al. 1998; and Evbuomwan and Anumba, 1998). For the purpose of this study, it could be summarized that integration can be defined as a integrative design development by bringing all multidisciplinary teams and functional background working in a structured, consistent and simultaneous approach in order to achieve more efficient and high performance project.

In the construction industry, the term of 'integration' has been used to describe a collaborative work environment culture created by all participants involved in a project either by individuals or organizations (Strategic Forum for Construction, 2003; Vyse, 2001). This culture is required in order to bring the various organizations that make up the project delivery team to work together more effectively as a single unit. An integrated delivery team for example, is a highly effective and efficient collaborative team that responsible for the design and construction of a project (Baiden et al. 2006). The team brings together various skills and knowledge, and removes the traditional barriers between those with responsibility for design and construction in a way which improves the effective and efficient delivery of the project (Achieving Excellence in Construction, 2003; Akintoye, 1994; Fleming and Koppelman, 1996).

Past researchers (Love et al. 2004; Anumba et al. 2002; Bromley et al. 2003; Cornick and Mather, 1999; Dainty et al. 2001; Evbuomwan and Anumba, 1998; Love and Gunasekaran, 1998; Moore and Dainty, 1999; Strategic Forum for Construction, 2003; and Vyse, 2001), has identified six main dimensions that describe a team that has been fully integrated. Following on from these findings and a review by Baiden et al. (2006), the delivery team in a construction project can be described as 'fully integrated' when it:

- has a single focus, and objectives for the project (Koutsikouri 2008; Kim and Kang, 2008; Strategic forum for construction, 2003; Baiden et al. 2003; Bromley et al. 2003; Holland et al. 2002; Anumba et al. 2002; Austin et al. 2002; Vyse, 2001; Cornick and Mather, 1999; Evbuomwan and Anumba, 1998)

- operates without boundaries among the various organization members and work towards mutually beneficial outcomes (Love et al. 2004; Strategic forum for construction, 2003; Baiden et al. 2003; Bromley et al. 2003; Vyse, 2001; Love and Gunasekaran, 1998)

- freely sharing information among its members such that access is easy and not restricted to specific professions and organisational units within the team (BuildOffsite, 2008; Kim and Kang, 2008; Baiden et al. 2003; Vyse, 2001; Cornick and Mather, 1999)

- has a new identity and is co-located (Strategic forum for construction, 2003; Bromley et al. 2003; Anumba et al. 2002; Austin et al. 2002)

- operates in an atmosphere where relationships are equitable, offers its members equal opportunities to contribute to the delivery process and all members are respected (Koutsikouri 2008; Kim and Kang, 2008; Baiden et al. 2003; Holland et al. 2002; Dainty et al. 2001; Vyse, 2001; Love and Gunasekaran, 1998)

- has a "no blame" culture (Koutsikouri 2008; Baiden et al. 2003; Holland et al. 2002; Strategic forum for construction, 2003; Dainty et al. 2001; Vyse, 2001)

These dimensions of integration are summarized in Table 1.

Table 1: Literature based analysis of dimensions of integration

	Author	Single team focus, and objectives	Seamless operation with no organizationally defined boundaries	Unrestricted cross-sharing of information	Creation of a single co-located team & office	Equitable team relationships and respect for all	'No blame culture'
Literature Source	Love *et al* (2004)		X			X	
	Strategic forum for construction (2003)	X	X		X		X
	Baiden *et al* (2003)	X	X	X		X	X
	Moore and Dainty (1999)	X		X	X		X
	Bromley *et al* (2003)	X	X	X	X		X
	Anumba *et al* (2002)	X			X		
	Dainty *et al* (2001)					X	X
	Vyse (2001)	X	X	X		X	X
	Cornick and Mather (1999)	X		X			
	Evbuomwan and Anumba (1998)			X			X
	Love and Gunasekaran (1998)	X					
	BuildOffsite (2008)			X			
	Austin *et al* (2005)	X			X	X	
	Kamara *et al* (2000)						
	Austin *et al* (2002)	X			X		
	Holland *et al* (2002)	X				X	X
	Kim and Kang (2008)	X		X		X	
	Koutsikouri *et al* (2008)	X				X	X

APPROACHES TOWARDS TEAM INTEGRATION

Attempts at team integration in the construction industry have been largely focused on improving project procurement and the product delivery processes (Baiden et al. 2003). An integrated procurement approach gives clients a single point of contact for both design and construction besides creates an opportunity to implement constructability principles early during design stage of project (Masterman, 2002; Trigunarsyah, 2006). In the constructability principle, it considers contractors' role early in the design thus results on more constructible design and greater amount of cost savings, labor savings and less substance wastages (Jergeas and Put, 2001; Trigunarsyah, 2006). Further, Russell (1994) highlighted that early involvement of construction knowledge and experience approach can reduce the likelihood of creating designs that cannot be efficiently built, thereby reducing design rework, improving project schedule, and establishing construction cost saving. For example, early involvement of contractor (ECI) has been selected as a contract delivery strategy towards integrated team and becoming more popular for a number of major construction projects especially in infrastructure (Edwards, 2007).

In addition, studies by Anumba et al. (2002); and Love and Gunasekaran (1998) discussed that design and construct strategies and partnering arrangements have been used to integrate the project delivery team in the traditional construction industry practice. Further exploration in terms of enhancing collaborative efforts could help the industry towards a more responsive environment. Partnering delivers significant improvements in performance by empowering designers and specialist to do their best work. Other key objectives in pursuing this approach include addressing opportunistic behavior, power imbalance and lack of equity, cost overruns, and contractual and confrontational procurement strategies leading to disputes. The partnering approach allows for a more consultative manner of working and aims at achieving common goals driving at win-win collaboration. The incorporation of strategic partnering in the IBS is seen to be a value added and strong approach to its implementation and project delivery. This is due to the nature of the IBS construction itself that requires close integration and cooperation among stakeholders with regard to the upstream and downstream relationship of the project delivery system.

Integrated forms of procurement, such as design and build, that bring together the design and construction phases of projects, have also been introduced (Bourn, 2001; Stutz, 2000; Mohammed, 1999; Bowron, 2002). Similarly, IPD Guide (2007) introduced a new integrated project delivery approach namely as 'Integrated Project Delivery' (IPD) purposely to integrate people, systems, business structures and practices into a construction process. In contrast to the traditional construction practice, the team members in IPD are demanded to work together concurrently either in a decision making process or when trouble arises throughout the design, fabrication, and construction phases.

On the other hand, the product delivery process has also been integrated to reduce the number of distinctive parties to a single all-inclusive party (Baiden, 2006). The several separate and phased processes involved have also been merged into system capable of delivering the same product in a single process. Those related approaches to improve team integration has been highlighted by previous researchers through the concept of concurrent engineering (Kamara et al. 2000; Evbuomwan and Anumba, 1998; Broughton, 1990); lean thinking (Huovila, et al. 1997; Matthews and Howell, 2005); 'using a boundary object' (Fong et al. 2007; Forgues and Koskela, 2009); and integrated supply chain management (Khalfan and McDermott, 2009; Love et al. 2003; Vrijhoef and Lauri Koskela, 1999).

Based on the above studies, it shows that an integrated delivery team is a highly effective to brings together various skills and knowledge, and removes the traditional barriers towards an effective and efficiency delivery of the project (Baiden et al. 2006; Achieving Excellence in Construction, 2003; Akintoye, 1994; Fleming and Koppelman, 1996). As highlighted before, the problem associated with the traditional construction process (conventional methods) are similar to IBS (i.e. rework, delay, dispute, wastage etc.). Consequently, the tools or strategies that are used to form or enhance integration of teams in traditional construction processes can also be applied in IBS projects to achieve effective team integration. These strategies could potentially overcome the constraints of IBS application in Malaysian construction projects.
The findings of previous studies discussed above have clearly indicated that there is some limitation on the subject matter. There is yet a study to develop tangible examples of 'full' integration or a study producing a list of key or critical success factors especially for Malaysian construction projects. Furthermore, current literature has explored numerous team integration frameworks, tools or strategies which identified varying advantages and disadvantages between them. With all of these contrasting information and knowledge, it could cause some amount of confusion for industry practitioners specifically for the Malaysian IBS stakeholders in choosing the most appropriate approach towards improved integrated team practice. Accordingly, research into integrated team practice is necessary in order to enhance the level of integration among stakeholders during the design stage if the full potential of IBS for both the industry and its clients is to be realised.

As a response to this challenge and consistent with needs of the current construction industry, therefore, this research paper is generated in order to focus on identifying the critical factors of an integrated team that improves effectiveness of teamwork particularly in the design stage of IBS projects. At this stage, this paper will discuss on the critical success factors (CSFs) that based on the literature review of previous studies as fundamental elements for this research in order to develop a framework to meet this need. According to the literature review and workshop, 9 critical success factors and 28 sub-factors (components) were identified as critical for an integrated IBS project. The factors have been grouped into three key elements: people, process and technology.

The 'people' in this research refers to the personal and human factors such as work attitude, accountability, organization and leadership. It implies that a project team needs to firstly develop its people capability in order to achieve an effective integrated team. While, in terms of 'process,' the existing design and construction process which is based on the traditional approach needs to be changed and geared more towards a collaborative and integrative practice. The transformation process should include improvement in transparent communication; policy; procurement and contracts; and operational. Finally, integrated team practice has to be supported by 'technology'. Technology has been distinguished as an appropriate medium or tool for improving team integration to support and synchronize all the project's information and activities as a whole. The detail descriptions of each factor are given in Table 2 below.

Table 2: Descriptions of CSFs to achieve an effective integrated design team delivery in Malaysian IBS projects

Factor		Descriptions	Sources
People	Personal working attitude	**Definition;** "A hypothetical construct that represents an individual's degree of like or dislike for work". **Sub factors (components);** • Commitment, motivation and continuity • Openness to learn with positive self-improvement	Koutsikouri, 2008; Holland et al., 2000; Jassawalla and Sashittal, 1998
	Team accountability	**Definition;** "All team stakeholders are responsible for the progress and performance of the project". **Sub factors (components);** • 'Sense of ownership' attitude • Clear roles and responsible with an agreement	IPD, 2007; Abdelhamid, 2007; Holland, 2000
	Team Base Organisation	**Definition;** "A group of people working in collaboratively under a flat and systematically structured and managed to pursue or carry out all defined tasks and goals". **Sub factors (components);** • Flat and direct organisation structure • Early and flexibility of involvement • Appropriate skill with transparent selection process	Baiden, 2006; Holland et al., 2000; Kahn, 1996
	Management of leadership	**Definition;** "Characteristics and capabilities of the team leader's skill and vision to manage and deliver team working culture in the project organization are communicated effectively to all members". **Sub factors (components);** • Senior and top management support (i.e. in terms of scheme and commitment) • Team empowerment (i.e. giving 'autonomy,' 'authority' or 'power' in terms of decision-making authority or responsibility) • Understand and maintain mutual team based benefits, risks, rewards & recognition; • Well education and training	Khang and Moe, 2008; Appelbaum, 2007; Turner and Muller, 2007; Baiden, 2006; Parker, 2003; Holland et al., 2000; Jassawalla and Sashittal, 1998; Belassi and Tuker, 1996; Denison et al., 1996.

Process	Transparent Communication	**Definitions;** "Commitment of open, frequent and genuine communication at all levels in the integrated design team organization". This communication process provides tangible opportunities and a channel for all members of the team to directly involve, and to directly input into, the project goals, changes in policies and procedures, status reports, etc. **Sub factors (component):** • Symbiotic Relationship • Informal communication and relationship • Mutual respect, trust and understanding	Koutsikouri, 2008; IPD, 2007; Smith, 2006; Anumba et al., 2002; and Bowron, 2002; Holland et al., 2000; Pinto and Slevin, 1987
	Policy	**Definition;** "A plan or course of action as a design team intended to influence and determine decisions, action and others matters towards successfully integrated practice". **Sub factors (components);** • Clearly vision and mission, • Insurance liability waiver policy • Clearly direction with a single goal (i.e. to meet client customer focus orientation	Nifa and Ahmed, 2010; UKCG, 2009; Baiden, 2006; IPD, 2007; Egan, 2002; Holland et al., 2000
	Procurement and contracts	**Definition;** "A process of obtaining or delivering the project task (such as design) that must be underpinned by contractual forms which encourage the parties (team members) to collaborate rather than in competition". **Sub factors (components);** • Two stages of tendering process • Single contractual and procedures approach • Relational and multi-entity contractual	Nawi & Lee, 2010; UKCG, 2009; Eriksson et al., 2007; Morledge et al., 2006; Kumaraswamy, 2002; Egan, 2002; Jones, 2000; Ngowi 2000
	Operational	**Definition;** "A process or series of actions towards collaborative work environment for achieving a successful integrated team". This factor includes steps, facility, environmental and space that required towards integrated approach. **Sub factors (components);** • Intensify planning with co-located of teams	Stapley, 2006; Baiden et al., 2006; Love et al., 2004; Strategic forum for construction, 2003; Bromley et al., 2003; Anumba et al., 2002; Austin et al., 2002; Holland, 2000; Pinto et al., 1993

		• Interaction space and utility • Non-operational boundary • Working integrative and concurrently • Collaborative, independence and supportive climate	
Technology	Appropriate Technology	**Definitions:** "Appropriate mechanism or medium to co-ordinate activity; enhance interaction and knowledge sharing within a project team". This factor including communication facility, tool or system need in order to coordinate the detailed design and construction information among team members. **Sub factors (components);** • Integrative mechanisms to co-ordinate activity and share knowledge (i.e. groupware system, integrated modeling software etc.) • Project management tool/ technique • Integrative networking system	Koutsikouri, 2008; Stough et al., 2000; Holland et al., 2000

All of the CSFs that were identified from the literature review of previous studies need to be validated with the Malaysian IBS industry to determine whether the factors are applicable to Malaysian IBS projects. This is the subject of a current research project at the University of Salford and Universiti Utara Malaysia, which involves multidisciplinary construction players especially the Malaysian IBS experts. Therefore, it should be noted that all of the identified factors will be subject to inclusion or exclusion at future validation stage of this study.

CONCLUSION

Although IBS has a solution towards improving constructions sustainability, the implementation of this system is still far reaching as it faces a lot of barriers like the lack of integration among stakeholders during design stage in the project life cycle. Therefore, an 'integrated project team' has been identified as one of the appropriate approaches that can provide an effective framework for integrating in order to overcome that problem. Unfortunately, the findings of the previous studies and tangible examples of 'full' integration, especially in the Malaysian construction industry, are limited. It is worsened by the literature review which explored team integration frameworks, tools or strategies as they identified varying advantages and disadvantages between them, which have led to confusion for Malaysian IBS practitioners as to how to select the best or most appropriate approach towards improved integrated team practice. In view of that, this type of research is needed in order to enhance the level of integration and communication within the team and process if the full potential of IBS concept for the industry and its clients is to be realized. Further, it is of interest to identify the key or critical success factors that are pertinent in improving the integration of design and construction activities, thus aiding communication and co-ordination among stakeholders involved during the design stage within IBS projects in the Malaysian construction industry.

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A STUDY ON THE TREND OF THE USE OF IBS COMPONENTS AND THE SETTING UP OF IBS MANUFACTURING FACTORIES IN THE MALAYSIAN CONSTRUCTION INDUSTRY

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Abstract
There is an urgent requirement for the building of affordable houses with the increase in demand for low-cost housing. The impact of the demand, made the government enforced the requirement to use IBS in the construction industry for government projects since 2008. This research paper studies the trend of the use of IBS components and identifies the factors required for the setting up IBS manufacturing factories in the Malaysian construction industry. Thus, appropriate technology is an important tool to push the development of the IBS components in the Malaysian construction industry. US, UK and Australia have achieved modular building standard while Malaysia is still in the hybridization phase. The IBS manufacturing have the unique approach of setting up in the construction industry. Thereby to understand the phenomenal factors of setting up IBS manufacturing factories; a pilot study was conducted with seven interviews; four from the IBS manufacturing players, two with academician and one from the government agency. Anecdotally, total number of IBS factory sites has increased from 21 in 2002 to 102 factories in the year 2009. From the evolution of the IBS manufacturing sector, the most favourable system used in the IBS component is the steel framing system and followed by the precast concrete system. Results from the qualitative survey showed that the main parameters affecting the setting up of the IBS manufacturing factories are appropriate technology, open manufacturing plant concept, capabilities of transportation and erection, best practice: design and build, and skilled workers.

Keywords: *Appropriate Technology, Affordable House, Hybridization, Industrialized Building System*

INTRODUCTION

Appropriate technology and global standardization has changed the past practices of the construction industry. This has affected the land resources, social environment and local skills to cater for the demand on various types of homes. In order to meet this demand the local authority must have precise and detailed knowledge of the needs of the lower income group to build affordable homes. There is a need to accelerate the development of construction industry and to ensure that the level of productivity of the construction industry is raised; thereby the need to import the construction technology from overseas especially from the United States of America (USA), the United Kingdom (UK) and Australia as reported by Badir et al. (2002) and Hashim et al. (2009). Sometimes the advanced technologies do not suit with the local condition on factors pertaining to the environment; level of workers' skills; knowledge and competence; venerable resources and competent manufacturer to fabricate the mass production as well as high-quality products.

Affordable homes are becoming a vital issue to meet the demand with an increasing population growth. Sebestyen (1998) claimed that one-third of the building constructed is for residential and one-fifth to one-third of gross fixed investments were made on residential construction, which is the largest sub-sector. With the industrializing of construction sector, houses can be produced in mass production. The industrialization is also characterized by modern design a method that uses scientific knowledge on structures, building physics, fire, and computer technology (Abdul-Aziz, 1994). Low cost houses in Malaysia can be classified into three (3) categories as in Table 1 (SPNB, 2010). Table 2 shows three (3) categorization of hardcore poor, poor and vulnerable poor of households' position by states. An analysis on the three categories of the total poor households shows that 229,723 may have difficulty to buy low cost house. The vulnerable poor households may be able to afford to own an affordable house if both parents are working.

The government has encouraged the construction industry to move towards Industrialized Building System (IBS) which can produce high volume of houses at affordable cost especially low-cost houses. Government agencies such as Jabatan Kerja Raya (JKR) and Construction Industry Development Board (CIDB); and researchers have played vital roles to educate the main players of the construction industry in the form of policies, financial incentives, strategy guidelines, workshops and seminars to increase the awareness among the end users and clients. Industrialization of high rise residential building components is critical to competitiveness and has become a new trend in order to solve the housing problem and meet the demand for affordable homes especially in big cities with limited space for development area. Almost all the major cities in Asia, residential buildings are characterized with high-rise and high density (Niu 2004). According to Barlow (1999), there is a need to explore the new methods, techniques and ways of working to deliver affordable houses. As reported by Doherty et al. (2008), the homeless phenomena generate the transition of 'planned' city to the 'post industrial' city. Thus the construction players have responded to this crisis by adopting prefabrication and by building a more uniform product (IBSD 2005).

Table 1. Categorization of Low Cost Houses

Type of House	Floor area (ft^2)	Price (Peninsular)	Price (Sabah & Sarawak)
Low cost	700	From RM35,000	From RM 50,000
Medium low cost	750	From RM50,000	From RM 70,000
Medium cost	800 & above	From RM80,000	From RM100,000

(Source: Syarikat Perumahan Negara Berhad; Affordable Own House Programme, 2010)

Table 2. Poor Households Position by States (As at 30 September 2009)

State	Hardcore Poor[1]	Poor[2]	Vulnerable Poor[3]	Total
Johor	1,502	2,542	5,555	9,599
Kedah	2,228	3,827	6,384	12,712
Kelantan	4,108	7,719	13,718	25,807
Melaka	474	1,157	2,925	4,556
Negeri Sembilan	394	801	3,408	4,618
Pahang	973	1,859	5,766	8,628
Perak	2,099	4,324	7,434	14,107
Perlis	439	1,225	3,290	5,129
Pulau Pinang	645	1,922	8,240	10,817
Sabah	18,295	15,746	13,820	47,862
Sarawak	12,537	14,528	18,740	45,805
Selangor	1,261	2,554	6,210	10,025
Terengganu	4,377	9,322	14,194	28,015
F.T. Kuala Lumpur	126	271	860	1,257
F.T. Labuan	61	206	514	781
F.T. Putrajaya	0	0	5	5
Total	49,519	68,003	111,063	229,723

Poverty Income line
[1] Household with monthly income below RM430 in Peninsular Malaysia and below RM540 in Sabah and Labuan as well as RM520 for Sarawak.
[2] Household with monthly income below RM720 in Peninsular Malaysia and below RM960 in Sabah and Labuan as well as RM830 for Sarawak.
[3] Household with monthly income above the Poverty Income Line and below RM1,500 in urban areas and RM1,000 in rural areas
(Source: Economic Report, MOF 2009/2010)

The Malaysian construction industry is undergoing a paradigm shift from using conventional technology to a more systematic and mechanized system that utilizes the latest information and communication technology. IBS has become a vital component in the industry to move towards global competition and update the new industrial trend. The advantages of using IBS in construction works are the reduction of unskilled workers, using optimum site materials, reducing environmental problems, maintaining the purity of construction sites and better quality control. Other added values of using the IBS in construction works is that the task becomes more organized and completion time of construction is reduced.

Even though, Malaysia is moving towards mass production of building components through industrialized building systems technology, but still faces constraint in terms of allocation for resources and material for site construction. IBS manufacturer plants are also finding ways to achieve a state where machines have high efficient ability and are able to perform repetitive tasks using standardized components. The government had enforced rules that require the construction industry to use IBS components. However, the problem is that there are few IBS manufacturing plants in Northern Peninsular Malaysia, Western Peninsular Malaysia, Sarawak and Sabah. This paper aims to analyze the trend of industrialized building system manufacturing plants in Malaysia and identify the main factors for setting up the best practice of IBS manufacturers in terms of appropriate technology in order to enhance the construction speed, quality and mass volume.

METHODOLOGY

The design of the pilot survey is a vital procedure to enhance the validity and reliability of the survey instrument. The respondents of the pilot survey will help to strengthen the content, scope, question structure and response scales. The approach used in the study was by interviews. The semi structured interviews were set based on the literature review from Oppenheim (1992), Naoum (1998) and Fellows and Liu, 2008. Qualitative approach is applied in the research, where the use of interview technique could generate a deeper depth of the research field but the scope covered is restricted to the knowledge and experience of those involved only. The key person involved in the interviews are four from the IBS manufacturing players, two academician and one from the government agency.

THE TREND OF IBS

The main function of the IBSs is to create synergy, by generating partners in the industry to assist in training, giving exposure on use of IBS techniques, encouraging the setting up of new IBS factories locally, updating on the latest technology, and enhancing current issues on IBS in the local state and international level (CIDB, 2003). The conventional construction method consists of extensive cast in situ activities being widely used and the huge quantities of unwanted materials cause difficult in controlling wastage in construction sites. Therefore, the prefabrication method using IBS is being widely used in European countries, Japan and Singapore as well as Malaysia (Tam et al., 2007). Through the industrialization of the construction industry, huge amount of work is shifted offsite, resulting in less labour is used on site, efficient use of materials and less wastage; and a tidier and cleaner construction sites (IBS, 2003).

The IBS components can be divided into a few categories and has undergone several changes following the new trend of technology. Table 3 described the trend of IBS since the early 60’s until 2009.

Table 3. Categorization of IBS Component

IBS Introduce in	Categorization of IBS	IBS Component
Early 60’s	Badir et al. (2002)	Frame System Panel System Box System
Early 90’s	Badir and Razali (1998)	Full prefabricated construction on site and off site: Precast concrete framing, panel and box systems Load bearing block Sandwich panel Steel frame
2003	CIDB (2003)	Pre-cast concrete framing, panel and box systems Formworks systems Steel framing systems Prefabricated timber framing systems Block work systems

(Source: Azman et al. 2009)

The evolution of IBS categorization relate with the expansion of IBS manufacturing. Table 4 shows the number of IBS manufacturing in 2009. The data sourced from CIDB shows that all the IBS manufactures registered with the CIDB list companies involved in IBS. The current total number of IBS manufacturer in Malaysia is 102. In the recent years, there are suppliers and manufacturers who are among the 21 which were actively involved in the dissemination of IBS in Malaysia (Badir et al., 2002). Majority of the IBS originated from the United States, Germany and Australia has a market share of 25%, 17% and 17% respectively. Malaysia produced about 12% of the IBS systems (Kadir et al., 2005). The growth of IBS has increased almost five times as reported by Azman et al. (2009). The highest number of IBS manufacturers can be found in the area of Selangor (49) followed by Kuala Lumpur (26) and Terengganu (5). Pulau Pinang, Melaka and Sabah is in the fifth place and has three IBS manufacturers. Perlis, Kedah and WP Labuan do not have any IBS manufacturer and this contribute to the reluctance of the contractors to use the IBS method due to the increase in transportation cost and miscellaneous cost. Similarly, the state of Pahang, Kelantan and Perak are still in the initial state to explore the use of IBS. Meanwhile Melaka and Negeri Sembilan have no problem to source the IBS components from the other states namely Selangor and Kuala Lumpur. The tremendous amount of emphasis for building construction activities has met the expected outcome of the Malaysia Eight Five-Year Plan. Yet, the government still requires an additional of 100,000 units of affordable homes to use IBS (IBSD, 2005).

Table 4 shows the number of IBS manufacturers grouped according to the classification. The highest numbers of IBS manufacturers are in the metal framing systems (i.e 24 numbers) category followed by precast concrete and timber framing manufacturers with 21 and16 manufacturers respectively. The lowest number of IBS manufacturer is block work systems (with 9 manufacturers). In the analysis, it was found that metal framing systems have become more popular compared to the precast concrete due to the time frame, cost effectiveness and quality impact of the completion project. The technology and expertise in the IBS construction industry have move forward to the fast-track lane. For future research work, it will be useful to study the demand of IBS components for each classification and to forecast the future expansion of the Malaysian construction industry.

Table 4. The Number of IBS Manufacturers in 2009

State	Precast Concrete	Panel	Formwork Systems	Timber Framing	On Site Manufacture	Metal Framing Systems	Blockwork Systems	Total
Perlis	0	0	0	0	0	0	0	0
Kedah	0	0	0	0	0	0	0	0
Pulau Pinang	0	0	0	0	0	2	1	3
Perak	1	0	0	0	0	1	0	2
Selangor	6	7	9	9	5	11	2	49
WP K.Lumpur	6	2	2	4	5	5	2	26
N. Sembilan	1	0	0	0	0	0	0	1
Melaka	2	0	0	1	0	0	0	3
Johor	1	0	1	0	0	2	0	4
Pahang	1	0	0	0	0	0	1	2
Terengganu	1	0	0	2	0	0	2	5
Kelantan	0	0	0	0	0	1	0	1
Sabah	0	1	0	0	0	1	1	3
WP Labuan	0	0	0	0	0	0	0	0
Sarawak	2	0	0	0	0	1	0	3
Total	21	10	12	16	10	24	9	102

(Source: Orange Book, 2009)

THE SETUP OF IBS MANUFACTURING FACTORIES AS AN INDUSTRIALISATION SOLUTION

Historically the construction industry in Malaysia basically consists of various processes, involving many parties and different stages of work. It involves the participation of various parties from various sectors in order to ensure the efficiency of the construction work carried out. According to Bannet and Grice (1990), the conventional construction approach, is based on the rigid separation of design and construction. The design team prepares detailed drawings, specification and Bill of Quantities. The tender documents are prepared and the contract will be awarded to the successful tendered/contractor. The contractor will then manage the construction projects by using the subcontractors. According to Alaghbari et al. (2007) research on the main factors causing the delay in construction in Malaysia are as follows:

- Financial difficulty, being the most influencing factor causing the delay in construction projects in Malaysia usually faced by the subcontractors and labourers /workers;
- Delay in the delivery of materials due to poor coordination and weak site management and, as a consequence, construction errors due to the site and coordination problem were the subsequent factors causing delay in the construction projects in Malaysia.

Although, Malaysia had initiated the usage of IBS since the 60's, the response from the construction industry to overcome the delay in construction projects as mentioned by Alaghbari et al. (2007) by using IBS was poor. The response from the construction industry changed when the government enforced the ruling in 2008, where use of a minimum of 70% IBS in government projects will receive 50 percent levy from the government. The IBS's Report (2008) also indicates that the awareness of the construction industry on IBS knowledge and its application increased between 2003 and 2008. The scenario of construction industry in Malaysia has changed by the implementation of the IBS technology initiated by the Construction Industry Development Board (CIDB) Malaysia. Prefabrication (IBS) has been successfully employed in the manufacturing of houses and multi-story industrial buildings (Ngowi et al. 2004). The Industrialization may eliminate various processes and gives focus on the four main IBS players consisting of the client, designer, manufacturer and contractor as shown in Figure 1. The best concepts regarding the centralization of the construction industry to achieve the international standard require having the three main fields in one company; the designer, manufacturer and contractor. They are able to control the quality of work and ensure cost effectiveness. The location of the manufacturer is important in order to make the critical decision on fixed investment of the best site selection (Eddie and Heng, 2004). On the selection of manufacturer location, the problems may involve a different set of criteria or objectives. According to Owen and Daskin (1998) on the site selection mathematical models; static and deterministic models have five basic purposes which focus on:

- How to minimize the average distance traveled
- How to achieve maximum coverage,
- How to determine a centre that can maximum coverage and minimize the distance traveled

- How to deal with multiple objectives and;
- How to locate undesirable location.

The models is a good guide for the future site selection conditions under two core uncertainty situations; planning with known model input parameter and planning imperfect information of input parameter (Eddie and Heng, 2004). Furthermore, for the advanced industrialized construction industry, its development has been classified into three (3) generation of industrialization (Ismail, 2006), as shown in Figure 2.

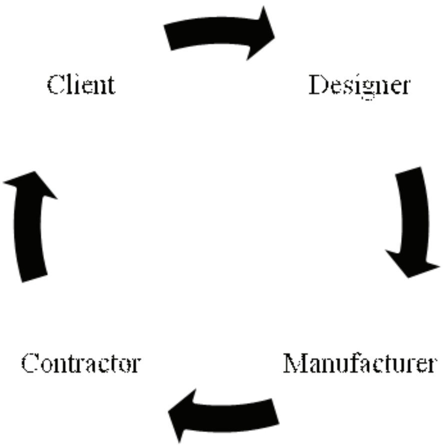

Figure 1. Successful IBS Players

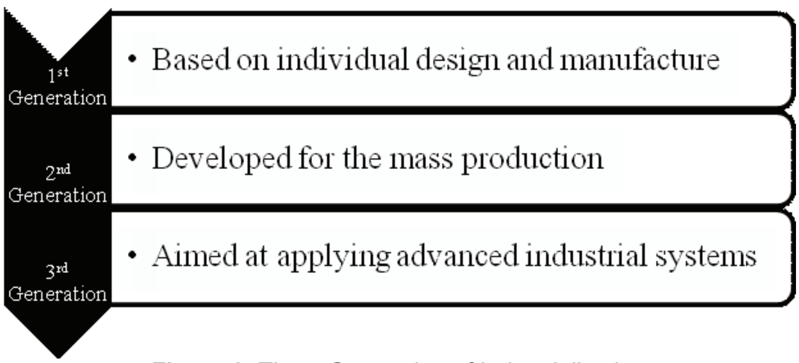

Figure 2. Three Generation of Industrialization

From the qualitative survey, the main factors identified for the setting up IBS manufacturers are as follows:

- Appropriate technology
- Open manufacturing plant
- Transportation of IBS components and erection
- Design and build
- Skilled workers

Appropriate Technology

The appropriate IBS technology to be use for the construction industry in Malaysia is the hybridization technology which is a combination of the small partial conventional method and the mechanization technology. It also reflects the latest IBS classification, which is the innovative product system (IBS info, 2010). According to Sebestyen (1998), the usage of mechanization such as mobile concrete mixers and tower crane provided the best solution for high rise residential buildings in France and Denmark as well as Hong Kong. Kamar, et al. (2009) mentioned that classification of IBS should be expanded to cater the scope of volumetric (modular) and hybrid construction. IBS is not to be seen as a threat to traditional methods. Both methods should be able to work in tandem and improve their processes collectively. The sharing of best practice between the two approaches is essential for the continued successful development of both construction sectors. Currently the most popular type of manufacturing in Malaysia is off-site which a significant distance from the site is. Offsite construction however, is remote from the building site prior to installation in their manufactured or assembled form. Thus the offsite can be divided into pre-assembly and on-site assembly. The relation is best shown in Figure 3 (Kamar et al. 2009).

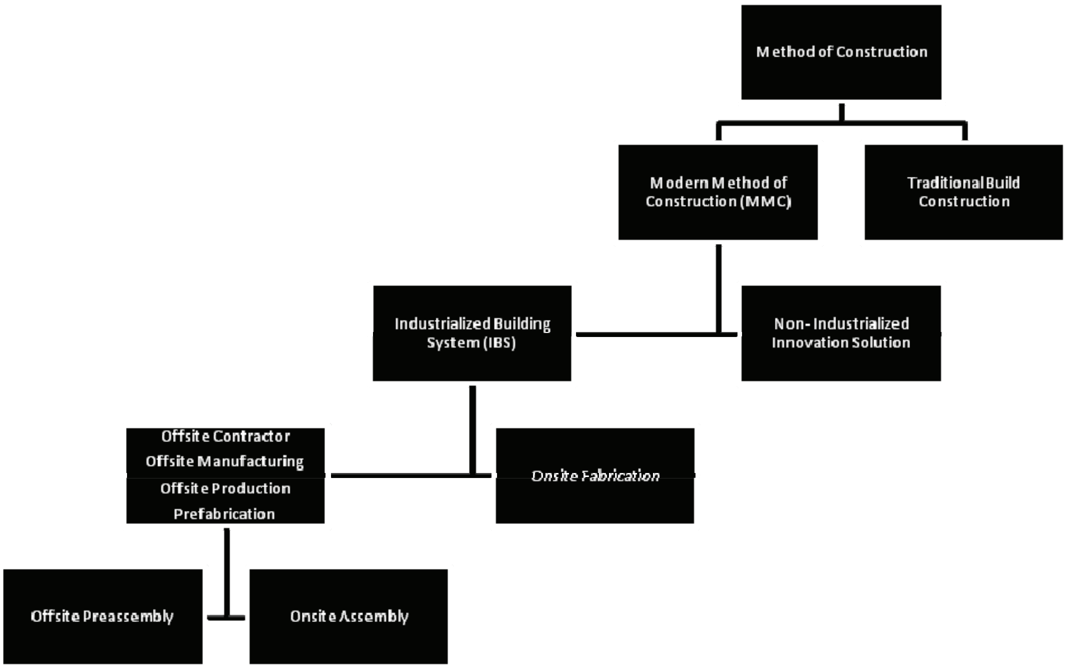

Figure 3. IBS and Other Terms to Describe Industrialisation in the Method of Construction (Source: Kamar et al. 2009)

Open Manufacturing Plant

Countries like Malaysia, with a tropical climate and temperature ranging from 22°-35°C has an advantage in applying the Open Manufacturing Plant. The types of IBS manufacturing system available in Malaysia are the Open Manufacturing System and Closed Manufacturing Plant System. The Open Manufacturing System are factories that do not have a building but possess heavy machineries, workers, place to locate raw material and an office. The conventional manufacturing systems have workers, capital and plant. The uniqueness of the Open Manufacturing System for the precast concrete system is its ability to obtain the natural curing concrete with a minimum grade of 30 in a 24 hours' delivery period and much suited to the tropical climate. The conventional construction works in Malaysia apply a normal concrete grade of 25. This procedure could not be applied in the IBS system because the concrete grade of 25 requires 48 hours of curing time before the precast component can be lifted and erected. Otherwise the precast component - may break upon lifting. The machine used by the IBS manufacturer is two 10 ton mobile cranes and one batching plant concrete. There are two main production systems focusing on IBS components consisting of linear or skeleton system, and planar or panel system. While the three dimensional or box system is excluded due to low demand, the panel system can be joined to form a box system to save cost on the mould. The Open Manufacturing system saves cost by 10 times compared to the normal factory system based on the interview with the IBS manufacturers.

Transportation of IBS Components and Erection

The significant value for each component of IBS precast concrete should not exceed more than 7 ton to ensure that the crane can easily erect and transport the material to the site. In Malaysia it is difficult to find heavy duty crane. The limitation radius of transporting IBS components to site is 50km. Meanwhile, the study by Warszawski (1999) on the suitable distance from the new potential development area to the fabrication plant should be the distance with a variance from 50km to 100km.

Apart from the effective distance to transport the IBS component to the site, it is also important to have the precast concrete in partial sizes where can be 'plug and play' to become large scale precast concrete. The main reason why the IBS manufacturer chooses to produce partial size of precast concrete is to enhance the effectiveness of erection, easy transportation to the site construction and save cost on hiring the appropriate crane The Figure 4 shows the IBS system sequence of works.

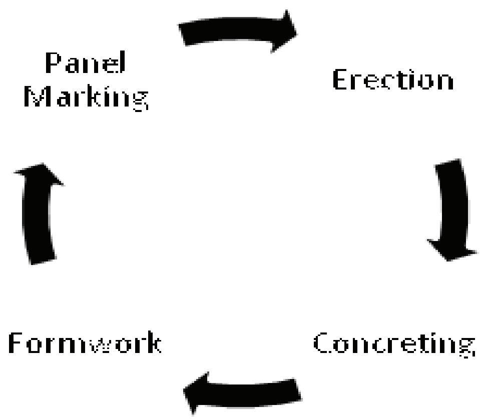

Figure 4. IBS System Sequence of Works

Design and Build

Figure 5 shows the construction project delivery by using the IBS system. The best practice tender award is design and builds using the IBS system. The Design and Build method would be able to control the whole project flow especially during the construction period with less change in the design stage. The design-build still produce the conventional method of drawing, and the IBS drawing will be produce while the earth-work and pilling section were conducted on site. Under the IBS method, the M&E drawings need to be inserted in the early stages. The process requires consultation with client to finalize the design. The effectiveness of the IBS drawing helps to eliminate the redundant work in conventional works especially in the superstructure stage. In normal situation, even in design-build contract using conventional method of construction, there are construction adjustment needed to be done during the substructure and superstructure of construction stage. This process delays the milestone project and incurred increment of the project cost. In contrast to IBS drawing system, once the concrete have been put to cast based on the final drawing, it is not viable to make any more adjustment except if the client agree with the additional cost imposed for the extra renovation work. That is why design and prefabrication need to be accurate at the IBS drawing design stage. The piling and the substructure work need to have a good setup and precise panel marking to avoid the displacement of structure when the component structured are installed. Basically the substructure of the project will used conventional method due to the limited repetition mould usage. It is also the best time to prepare the fabrication mould for the superstructure which uses repetitive mould highly.

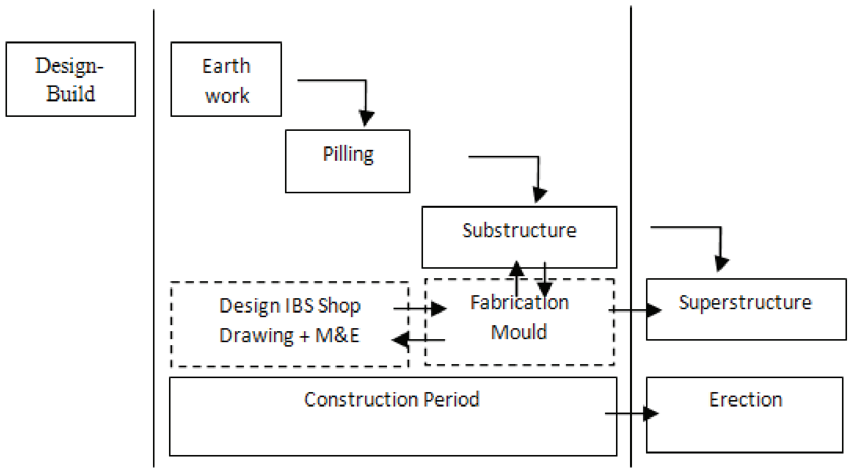

Figure 5. Construction Project Delivery Using IBS System

Construction Workers

As reported by Nadim and Goulding (2009); Blismas and Wakefield (2008); and Pan et al. (2007), the construction industry in UK and Australia are facing prominent shortage of skilled workers especially in the remote areas and high growth capital cities. Associated with the difficult situation, the traditional tradesmen also find difficulty to fulfill the requirement for higher onsite precision and to deal with the low tolerance of the tasks. The same situation also happened in Malaysia where the construction industry player foresees the need to train the unskilled workers to skilled workers to fulfill the demand. Although

Malaysia can easily attract foreign workers to work here, but due to the huge number of foreign workers working in Malaysia affecting the employment opportunities for the locals. By using the IBS method, Malaysia was able to reduce the number of foreign workers in 2006 by 4% as shown in Table 4 and to educate the industry that with the appropriate use of technology and systematic work, the use of IBS can gain the same productivity but with better outcome.

Table 4. Percentage of Foreign Workers to Total Construction Workforce

Items	2003	2004	2005	2006
Local Workforce	224,877	272,053	334,704	309,528
Foreign Workers	231,184	265,925	264,853	281,780
Total	456,061	537,978	599,557	591,308
Percentage of Foreign Workers	51%	49%	48%	44%

(Source: Department of Immigration Malaysia (MOF, 2005) and Construction Industry Development Board (CIDB) Malaysia)

CONCLUSION

The trend or change in the pattern of the IBS industry has gone through a few transitions from the conventional method to the hybridization stages. The government has introduce the IBS in the 60s but the response from the industry was poor as mentioned in IBS survey (2005); and the dramatic transformation in the use of IBS in 2008 only occurred after the government enforced the use of IBS in the construction industry for the government projects. The metal framing system is the most popularly use IBS in the construction industry based on the statistical analysis and also verification from the IBS survey 2003 and IBS survey 2008. The government needs to be responsive to this phenomenal change and provide more capital investment for automation and robotics technology in order to make Malaysia ahead in the transformation of the IBS construction industry. In addition, Slaunghter (1997) have done the analysis based on the research on 85 construction works using automation and robotics technology in Japan, European, US, Australia and Israel. The research examines the trend in the development of construction technologies and the attributes of the technologies that usually requires a higher degree of customization through the manipulation of standardized materials into nonstandard sizes or other adjustments. The flexibility to meet the unique requirements for each construction structure is achieved by modifying the standardized materials rather than producing other sizes through multi task machines.

Although technology is vital to accelerate the development of a country but it required the appropriate technology as one of the major factor in setting up IBS manufacturing, based on the qualitative survey. The other factors are open manufacturing plant which is more mobile and easy to move to nearest the project. The major component of the IBS manufacturing is still mobile to move to potential development area. The IBS manufacturing also need to have the capabilities to transport the IBS component economically, with breaking the size into part as well as having good skills in erecting the IBS components. Even though, the IBS players have the ability to run the practicality onsite, but they are also required to convert the conventional drawing to IBS drawing which is among the major challenge in using the IBS system. The best approach is to have the full control onsite by using the design and builds approach of tender award. Malaysia has a lot of foreign workers and managed to reduce the number of unskilled workers. Skilled workers are important in the IBS industry to ensure better precision works.

In conclusion, the IBS technology must be affordable to the construction industry especially for the small contractors; to reduce the knowledge gap between the designer and contractor to apply it under the Malaysian condition; ability to suit to the climatic condition in Malaysia which is heavy rain and hot weather; the concern of maintenance cost; and future research should be continued to educate IBS players.

ACKNOWLEDGMENT

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BEHAVIOUR OF BURIED PIPES DUE TO INTERNAL EXPLOSION

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Abstract
In this paper, the response of buried empty pipes due to internal explosion has been studied owing to the capabilities of finite element software, Abaqus Explicit. Using US Army Technical Manual, 1990, blast energies in three different size of pipes namely 0.8m, 1.0m, and 1.2m diameter were estimated for the three commonly used explosives namely 50, 100, 250kg TNT. Response of modeled steel and concrete pipes buried in loose sand, dense sand and undrained clay at different depth were examined. Results of this research has established from a total of fifteen (15) models studied that, given the same type of explosive, as the diameter of pipes reduces, pressures generated increases. In addition, under the impact of surface static loading, at burial depth to pipe diameter (H/D) ratio of 1, pressures, stresses, mises, and displacements are highest at the spring-line and least at the invert of the pipe. Furthermore, at H/D=2, the above mentioned parameter reduces, beyond which no significant responses occurred. Consequently, given the same type of explosive, steel and concrete pipe diameter and soil media, external work and energies generated in concrete pipes is much higher than that of steel pipes and increases in the same proportion as the thickness of pipes reduces. Finally, depth of burial and geotechnical properties of soil has no significant effect on the response of steel and concrete pipes.

Keywords: *Explosion, Energy, Pipes, Underground, Environment*

INTRODUCTION

Cylindrical shapes like pipes, tunnels, etc are used for different purposes across the globe. Pipes are generally used water supply, sewerage, irrigation, storm, industrial and domestic waste, oil and gas, etc while tunnels are used for transportations, etc. The main sources of blast in pipes are; accumulation of explosive gas in pipes during two phase flow (liquid and gas) especially in bends, leakage from reciprocating compressor catching fire and exploding, terrorists' attacks, wars, etc. Most importantly is to consider the severity of destruction of explosion due to blast. Blast can create sufficient tremors to damage substructures over a large area. The resultant of blast wave is peak overpressure which is the extent the pressure in the blast wave exceed atmospheric pressure of 10^5 Pa (1 bar). It has been reported that at 138kPa of blast wave, reinforced concrete structures will be leveled (Marusek, 2008). Consequent upon this are destructions of lives and property, land degradation, ecologic disaster, to mention a few. In the study of soil-pipe interaction through modeling, some parameters need to be incorporated. This is to simulate the existing situations between all the constituent materials **(**Ganesan, 2000). To this end, data are required and these could be obtained from field tests, laboratory tests, theoretical studies, work done in related fields and extension of work done in related fields.

A lot of works have been done on dynamic soil-structure interaction. Majorly for linear, homogeneous, and semi-infinite half space. The response of elastic half space was first carried out by Lamb (1904). Converse (1953) derived empirical relation for the determination of resonance frequency in vibrated soil. It was discovered that softer soils have lower natural frequency. The natural frequency is higher at lower bearing pressures on soil. Hard clays have less natural frequency than sand stones. Ronanki (1997) studied the responses of buried circular pipes under three-dimensional seismic loading. Method used is the finite element based software package, SAP-80. Parametric studies were equally carried out for buried pipes under both surface static and seismic loads. Ngo et al. (2007), Bibiana et al. (2008) and Remennikov (2003) gave the overview of the explosive loads characterization, blast energy and blast effects on structures. Marusek (2008) studied underground shelters due to blast loadings. Blast loadings were due to conventional weapon detonation. Finite element analysis software, Abaqus was used to carry out the analysis. Elasticity was chosen to model the behavior of the soil material. Blast load was represented as short duration. Parametric studies were equally carried out. Lastly, Husabei Liu (2009) recently used Abaqus, a finite element based software to obtain responses of subway structures under blast loading. The subway was placed in different soil layers and numerical simulations carried out. Mitigation measure used to improve ground stiffness and strength was also analyzed. This study is aimed at studying the response of underground pipes due to internal blast load with a view to providing guidelines for the design of buried pipes to resist the effects of blast.

CONSTITUENTS OF THE BLAST

In underground structures (i. e. pipes), the constituents of the blast comprises of the ground medium (rock and/or soil), intervening medium surrounding the structure, structures, blast and blast characteristics.

ROCK/GROUND MEDIA

The rock media depends on the geotechnical properties of the ground medium which ranges from intact rocks like schist to average quality to poor quality rocks. Rocks are formed as a result of various natural processes. The processes are the cooling of molten magma, the precipitation of inorganic materials, the deposition of shells of various organisms, etc. Rocks are classified into three; igneous rocks, e.g. granite, volcanic-basalt, etc, sedimentary rocks, e.g. sandstone, limestone, shale, conglomerate, or metamorphic rocks, e.g. schist, slate.

SOILS

Soil is a material which disintegrates into individual grains by mechanical means. Examples of mechanical means are agitation in water, application of flow pressure, etc. Soils are identified by various methods. These are: Bureau of Soils (1890-1895), Atterberg 1905, and MIT 1931. It also includes USDA 1938, AASHO 1970, and Unified Soil Classification System 1952. Soils range from dense sandy soils to saturated soft soils. There are three major types of soils. These are; frictional soils ($\emptyset \neq 0, C = 0$), cohesive soils ($\emptyset = 0$, $C \neq 0$), and frictional-cohesive soils ($C \neq 0$, $\emptyset \neq 0$). C is cohesion while $\emptyset$ is angle of shearing resistance of the soil. Cohesive soils contain clay minerals. The major groups of clay minerals are montmorillonites, kaolinites and illites. The minor groups are allophone, chlorite, vermiculite, attapulgite, palygorkite, and sepiolite. The soil material constants and expressions for their evaluation are:

Young's modulus, $E = \frac{\mu(3\lambda+2\mu)}{\lambda+\mu}$, (1) Poisson's ratio, $\nu = \frac{\lambda}{2(\lambda+\mu)} = \frac{Lateral\ strain}{Axial\ strain}$ (2)

Lame's constants – Shear modulus, $\mu = \frac{E}{2\,(1+\nu\,)}$ (3) and $\lambda = \frac{\nu\, E}{(1+\nu)(1-2\nu)}$ (4)

In the study of response of underground structures due to blast load, in this case by modeling, it must be remembered that possible ground media must be adequately covered. Homogeneous, isotropic loose sand, dense sand and undrained clay were the most possible ground media in Malaysia and other tropical regions like Nigeria, Ghana, etc since pipes are seldom laid in rocks. Under static elastic behavior, stiffness property and Poisson's ration are required while in dynamic elastic behavior; density, stiffness property and Poisson's ratio are required. Poisson's ratio fluctuates for different materials over a narrow range. Generally it is in the order of 0.2 to 0.5. The largest possible value is 0.5 and is normally attained during plastic flow and signifies constancy of volume (Chen, 1995). The adopted constitutive relations of soils are elastic, elasto-plastic, or visco-elastic though other complex relation like half space has been proposed. When soil is excited by a large explosion, it behaves nonlinearly. This behavior is usually described in terms of plasticity. In the case of visco-elastic soils, it is elastic when loaded which is accompanied by a slow and continuous increase of strain. If blast occurs, the material within the vicinity of the explosion will be subjected to plastic deformation (plastic strain), further away, it will be elastic deformation. Non-linearity in elastoplastic response of underground pipes due to blast effects should be considered. However, if the detonation is far away from the pipes or the materials and thickness of the steel and concrete pipes can absorb the wave energy propagated, nonlinear effects could be neglected and this validates the linear analysis without damping (Duhee et al. 2009). This means that steel and concrete pipe materials and the thicknesses considered has enough stiffness to absorb the wave propagated as a result of the explosion so as not to cause plastic deformation. Concrete and steel could be considered finite similar to hard impermeable stratum. For the behavior of undrained clay, dense sand, loose sand, steel pipe, and concrete pipe, strength of soil was not considered in the static and dynamic analysis because soil-pipe interaction do not depend on strength but on stiffness. Instead, stiffness, Poisson's ratio and density were considered. Heavy rainfall is predominant in the tropical region. Some areas in the tropics experience rainfall through out the year round. To capture this effect, saturated parameters of soils were considered to simulate the time during and shortly after rainfall before consolidation.

THE THIN-LAYER ELEMENTS SURROUNDING THE STRUCTURE

This could be considered in large cylindrical underground storage tanks or pipes lay in shallow trenches by using dense sand in other for arching effects to take place. Earth arching increases the load-carrying capability of buried structures. It allows the soil to redistribute the blast load evenly into "arches". This medium is not included in the analysis in the first instance since they fall within the three types of soil considered.

THE STRUCTURE

In this case, underground steel and concrete pipes. In the tropical areas, majorly steel and concrete pipes of different diameters are used to carry water, fluids, gases, etc in the ground and these pipes are seldom laid in rocks. The steel and concrete materials of the pipes are much harder than the soil medium, the pure elastic model without damping could be justifiably considered in this study. For the interface between soil and steel or concrete pipe, cohesive force (c) and dilation angle (δ) exist between soil and surrounding geological medium while cohesive force (c) and angle of shearing resistance ($\emptyset$) are those of the geological medium. Void/gap formation at the soil-pipe interface may occur when underground pipes are subjected to blast loadings. This is not taken into consideration in this study because the soil is assumed to adhere (gripped) to the surface of the pipe so that there will be no slip. There are other types of pipes of varying diameters, e.g. polyvinyl chloride (pvc) pipes, clay pipes, glass fibre pipes, etc. The soil, steel and concrete material values used in this study as obtained from Shacklock (1974), Ola (1983), Craig (1994), BS 8110 (1997), Gravessmith (1985), Olarewaju (2008), and Husabei (2009) are presented in Tables 1 and 2.

Table 1. Material Property for Soil

	Young's Modulus E (Mpa)	Poisson' Ratio (υ)	Density (kg/m^3)
Undrained Clay	6.0	0.5	2060
Loose Sand	10	0.3	1733
Dense Sand	30	0.3	1733

Table 2. Material Property for Steel and Concrete Pipes

	Young's Modulus E (Mpa)	Poisson' Ratio (υ)	Density (kg/m^3)
Steel Pipe	200×10^3	0.2	7951
Concrete Pipe	28×10^3	0.3	2400

BLAST LOADS

The majority of explosives are formed from Carbon, Hydrogen, Nitrogen and Oxygen. The general chemical formula is $C_x H_y N_w O_z$. TNT (trinitrotoluene) equivalent values are used to relate the performance of different explosives (hydrocarbon fuel inclusive). This is the mass of TNT that would give the same blast performance as the mass of the explosive compound in question. Details of conversion factors for various explosives are given by Remennikov (2003). Charge weight 25, 50, 250 and 500 kg TNT explosives at various stand-off distances are typical sizes for different explosive delivery methods ranging from a small hand-delivery bomb to a moving vehicle laden with high explosives. There are three methods for predicting blast effects on structures; these are empirical, semi-empirical and numerical methods. The empirical method is based on US Army Technical Manuals and Unified Facilities Criteria (2008). These are the most widely used publications available for designing protective structures. It contains the step-by-step analysis and design procedures. The design curve obtained from the US Technical Manual (1990) and UFC 2008 which gives the blast wave parameters is used in this study. The range of explosives considered for 0.8m, 1.0m, and 1.2m diameter pipes are 50kg TNT, 100kg TNT, and 250kg TNT. For all these pipes and explosives, incident pressure and peak reflected pressure were obtained. The effects of incident angle on reflected pressure were not considered since only one location was considered. This and other shock wave parameters can alternatively be used to estimate blast pressure and impulse. If explosion occurs in an exposed empty pipe, or pipe laid on the ground surface, it becomes surface blast. In this study, interest is in the response of underground empty pipes due to internal explosion. Detonation of an explosive charge in an empty underground pipe produces a radialy expanding compressive wave which propagates in the pipe and through the pipe and soil medium. When there is no buried structure in the soil, the pressure generated by the compressive wave is referred to as the free-field pressure.

PROCEDURE OF ANALYSIS

There are numerous numerical methods that could be applied to solve dynamic problems. These are iteration, series methods, weighted residuals (least square methods), finite increment techniques (step by step integration procedure) usually referred to as finite difference, Newmark, Wilson, Houbolt, Eular, Runge-Kuta and Theta methods. Finite difference is popularly used to solve ordinary and partial differential equations, in particular, dynamic problems. Using this method, solution domain is replaced by a number of discrete points called mesh points or nodes. Solution to the problem is obtained at these points by converting the differential equation into an algebraic equation approximately satisfying the differential equation and the boundary conditions. The algebraic equations can be obtained in terms of forward, backward or central difference formulae but central difference formulae are preferred due to their higher accuracy. The difference operator can be obtained easily using Taylor's series expansion of the unknown function. In the central difference equations for a function U (t), in which the grid points, (i = 1, 2…n) along the independent coordinate, t are equally spaced with step length Δt = h, using Taylor's series, values of functions U_{i+1} and U_{i-1} can be expressed in terms of U_i as

$$U_{i+1} = U_i + h\mathring{U}_i + \frac{h^2}{2!}\ddot{U}_i + \ldots \quad (5)$$

$$U_{i-1} = U_i - h\mathring{U}_i + \frac{h^2}{2!}\ddot{U}_i + \ldots \quad (6)$$

$$\mathring{U}_i = \left|\frac{du}{dt}\right|_{i=t} = \frac{1}{2h}(U_{i+1} - U_{i-1}) + 0(h^2) \quad (7)$$

$$\ddot{U}_i = \left|\frac{du}{dt^2}\right|_{i=ti} = \frac{1}{h^2}(U_{i+1} - 2U_i + U_{i-1}) + 0(h^2) \quad (8)$$

Most of the numerical methods in dynamic analysis are based on finite difference approach. The equation of motion is given as

$$[m]\,[\ddot{U}] + [c]\,[\mathring{U}] + [k]\,[U] = [P] \quad (9)$$

$$\text{For } U\,(t = 0) = U_o \quad (10)$$

$$\mathring{U}\,(t = 0) = \mathring{U}_o = v_o \quad (11)$$

The time duration (time period) for the numerical solution can be divided into n intervals of time Δt (h). It should be noted that $\Delta t \le \Delta t_{cr}$t $(=\frac{\tau n}{\pi})$ for stable and satisfactory solution. Δt_{cr} is the critical time step and τ_n is the natural period of the system $(=\frac{\omega n}{2\pi})$, ω_n is the natural frequency of the smallest of such period in the case of multi degree of freedom system. The accuracy of the solution depends on the time step Δt = h. However, there are some conditionally stable methods where any time step can be chosen on consideration of accuracy only and need not consider stability aspect. Accordingly, the unconditionally stable methods allow a much larger step for any given accuracy. Replacing Eq. 9 by Eqs. 7 and 8, we have

$$m \frac{(Ui+1 - 2Ui + Ui - 1)}{(\Delta t)^2} + c \frac{(Ui+1 - Ui - 1)}{2\Delta t} + k U_i = P_i \qquad (12)$$

where $U_i = U(t_i)$ and U_{i+1} can be written as

$$U_{i+1} = \frac{1}{(\frac{m}{h^2} + \frac{c}{2h})} ((\frac{2m}{h^2} - k)U_i + (\frac{c}{2h} - \frac{m}{h^2})U_{i-1} + P_i) \qquad (13)$$

This is the recurrence formula which gives the value of U_{i+1} in terms of U_i, U_{i-1} and P_i. Repeated use of the recurrence equation gives the response of U of the system in the entire domain of interest. This is also called an explicit integration method since U_{i+1} is obtained by using the dynamic equilibrium of the system at t_i as given in Eq. 12. The solution can not start by itself, because to obtain U_i (i = 0) from Eq 13, there is need to get the values U_o and U_{-1}. U_o is given by the initial condition in Eq. 10, U_{-1} has to be generated using the other initial conditions $\mathring{U}_o$ given by Eq. 11 and the governing equation of motion (Eq. 9) is given by

$$\ddot{U}_o = (m)^{-1} (P_o - c\mathring{U}_o - kU_o) \qquad (14)$$

From the difference equations, we obtained

$$U_{-1} = Uo - h\mathring{U}_o + \frac{h^2}{2}\ddot{U}_o \qquad (15)$$

Where $\ddot{U}_o$ is known from the given initial conditions as expressed by Eq 14. This is better solved using Abaqus dynamic explicit which uses explicit central difference operator that satisfies the dynamic equilibrium equations at the beginning of the increment, t, the acceleration calculated at time, t are used to advance the velocity solution to time, $t + \frac{\Delta}{2}$ and displacement solution to time, $t + \Delta t$ '(Kameswara, 1997; Abaqus User's Manual, 2009)'. Abaqus/Dynamic Implicit analysis is used to study (strongly) nonlinear transient dynamic response.

Dynamic Explicit are used for the analysis of large models with relative short dynamic response times and extremely discontinuous events or processes. It allows for definition of very general contact conditions. It uses a consistence large deformation theory. This justifies the use of Dynamic Explicit for the present study. In this study, for sensitivity, the time period is 0.025 for automatic incrementation, and unlimited maximum time increment. For stability, global stable increment estimator was adopted with time scaling factor of 1. Linear bulk viscosity parameter is 0.06 while quadratic bulk viscosity parameter is 1.2. Frequency is evenly spaced time interval at interval of 20. Static analysis in Abaqus standard was used to validate the work by Ronanki (1997) in the study of the response of buried pipe due to surface static load. Abaqus/Standard uses direct-integration dynamic analysis because there is no solution for a set of simultaneous equations. The analysis focused on modular ratio, soil type, pressure, displacement, strain and Mises in pipe. The von Mises theory is simply one of the several failure theories used to determine the applied stress in a member. It combines principal stresses, from Mohr's Circle, into an equivalent applied stress which is compared to the allowable stress of the material. The yield stresss is a known property of the material, and is usually considered to be failure stress. The equivalent stress is often called "Von Mises Stresses" as a shorthand description. It is not really a stress, but a number that is used as an index. If "Von Mises Stress" exceeds the yield stress, then the material is considered to be at failure condition. The von Mises theory is used for ductile materials and is seen most often when evaluating stresses, both static and dynamic. Equivalent stress or Von Mises stress, σe, is determined from the stress state as,

$$\sigma e, = \sqrt{\frac{1}{2}((\sigma x - \sigma y)^2 + (\sigma y - \sigma z)^2 + (\sigma z = \sigma x)^2)} \quad (16)$$

Where $\sigma x, \sigma y, and\ \sigma z$ are the 3-dimensional principal stresses from Mohr's circle.

FINITE ELEMENT MODEL

The existing model of the work by Ronanki (1997) under the impact of surface static pressure using SAP program (no numerical data available) was verified using a finite element numerical code, Abaqus Standard to obtain the displacement, pressure, etc. The governing equation of motion in matrix form is expressed in Eq. 7. m, c, and k are element mass, damping and stiffness matrices. U and P are displacement and load vectors (are time dependent). Dots indicate their time derivatives. After incorporating the damping,

$[c] = \alpha$ [K] + β [m] (17)

α = the stiffness damping constant. β = the mass proportional damping constant. Ü = Second derivative of vertical displacement with respect to time (acceleration vector), Ů = First derivative of vertical displacement with respect to time (velocity vector), U = Vertical displacement vector, and t = time (s)

Stiffness matrix of the element, $[K^e] = \int_{-1}^{+1}\int_{-1}^{+1}\int_{-1}^{+1}[B]^T$ [E] [B] $\| J \|$ dζdn dξ, (18)

$\| J \|$ is the determinant of Jacobian, $[B]$ is the strain nodal displacement matrix and [E] is elasticity matrix.

Element mass matrix, $[M^e] = \int_{-1}^{+1}\int_{-1}^{+1}\int_{-1}^{+1}\rho[N]^T[N \| J \|$ dζdn dξ, (19)

ρ is soil density. $[N]$ is the mapping function. The global matrices in the transformed domain are computed directly.

Basically there are two types of damping in soil dynamics: geometric damping and material damping. Geometric damping is as result of wave energy and amplitude lost by radiating waves moving out of the vibrating structure. These waves are gradually disappearing in the infinite soil medium. This is because reflection is not possible due to infiniteness. It is loss of energy due to propagation of waves to the infinite boundary (Fig. 1b). Material damping is the resistance in the material of the medium. This could be represented as *viscous damping*. If the damping ratio is zero (0), then there is no damping at all, the soil is purely elastic. As the damping ratio increases, pressure generated as a result of wave propagation reduces, with maximum pressure at damping ratio equals to zero (0)

(Zhengwen, 1997). This validates the worst scenario of maximum pressure with zero damping. Lastly the force vector in global form is computed. The stiffness matrix K, the mass matrix M and the force vector P of the whole system are obtained. This is by combining the respective matrices of the soil-structure system. The damping matrix C is obtained in a similar coupling process. This is by combining the damping matrices which are established with the Rayleigh damping assumption (Tian and Li, 2008); (Kameswara, 1998).

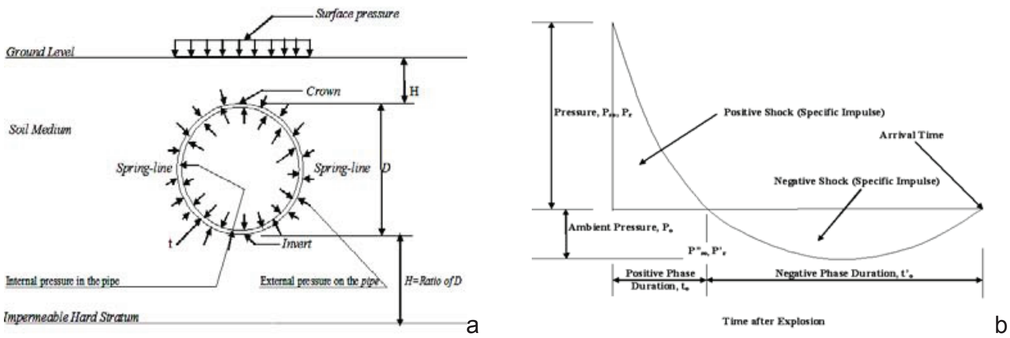


Figure 1. Soil and pipe model: (a) Cross-section of buried pipe; (b) Pressure-time variation

MODELING OF MATERIALS

East and West Malaysia is located in the tropical region and the geological condition is similar to West African countries like Nigeria, Ghana, Senegal, Gambia, etc, and other part of the world in the tropical region (Ola, 1983). In these areas, majorly steel and concrete pipes are used to convey fluids, gases, etc in the ground. Pipes are seldom laid in rocks in the tropical regions. It is justified to consider undrained behavior of clay since the movement of pore water is negligible under both rapid static and blast loading. But for low continuous static loading, movement of pore water should be considered. The effects of practically unbounded domain of soil need to be considered in analyzing dynamic soil-structure interaction problem. This could be done by considering the soil as semi-infinite medium with unbounded domain. For static loading, a fictitious boundary can be introduced at a distance from the structure where the load effects can be expected to be practically negligible. This leads to a finite domain for the soil which can be modeled by finite elements similarly to the structure. However, for dynamic loading, this procedure generally can not be used because a fictitious boundary reflect waves originating from the vibrating structure back into the discretized soil region instead of letting them pass through and propagate toward infinity.

In the case of blast loading whose acting duration is very short, the initial stage of the response is of great interest and a fictitious boundary could be set at a sufficient distance away where either the reflective waves are not produced within the duration of interest or the effect of reflection on the response is so small that it can be neglected. In this study, the ends of the soil medium were considered to be far away from the explosion, no fictitious boundary was introduced. To model the behavior of dense sandy soil, undrained clay soil, steel and concrete pipes, strength of soil was not considered in the static and dynamic analysis because soil-pipe interaction do not depend on strength but on stiffness. Instead, stiffness, Poisson's ratio and density were considered. Non-linearity in elastoplastic response of underground pipes to blast effects should be considered. However, if the detonation is far away from the pipes or the materials and thickness of the steel and concrete pipes can absorb the wave energy propagated, nonlinear effects could be neglected and this validates the linear analysis. This means that steel and concrete pipe materials and the thicknesses considered has enough stiffness to absorb the wave propagated as a result of the explosion so as not to cause plastic deformation.

The choice of material model is based primarily on the purpose of analysis. In the verification of existing model under surface static load, a homogeneous soil with smooth and rigid boundaries having a width of 7.30m, depth of 4.8m and 10m long contained a 0.96m diameter pipe embedded initially at H/D = 1 (Fig. 1a). Pipe is assumed to be horizontal with no slip between the pipe and the soil. Surface static pressure load of 10Pa was applied to the surface of the soil. The Young's modulus of soil, E_s is 1 x 10^4Pa, Poisson's ratio, v, is 0.3 while the Young's modulus of pipe E_p is 1 x 10^6Pa and Poisson's ratio, v, is 0.2. The plane stress/strain thickness is 1. Different depths of embedment were considered. The analysis step type is general static since the soil will be loaded at the top. Time period is 1, maximum number of increments is 100 with initial, minimum and maximum increment size of 0.1, 1E-005, and 1 respectively using direct equation solver method. Consequent upon these is the formation of C3D8I, an 8-noded linear brick, incompatible nodes. With an approximate global size of 1.75, and to ensure convergence during analysis, 258 hex elements were generated for the model. In the work of Ronanki (1997) which is based on both 3-dimensional surface static and seismic loadings on underground pipes, 256 elements were generated using SAP-80 program. Large finite element model was used in other to have clearer picture of the three-dimensional response of the pipe. The boundary conditions of the finite element model for displacements were fixed (at the base) and roller on other sides. Zero initial conditions were used in all calculations.

In the present study of explosion due to internal explosion in buried pipes, the finite element model of all the soils (undrained clay, lose sand and dense sand) is 21.04m width, 8.04m depth and 20m long. Steel and concrete pipes are 1.0m diameter and 20m long. 0.010m and 0.020m thicknesses were considered. Pipes were laid horizontally each at 3.04m and 6.04m depths in other to consider various embedments with no slip assumption. The pressure was assumed to be the normally reflected pressure. One explosive that fall within the equivalent of those normally used by terrorists was used to study the response of buried steel and concrete pipes. The explosion was assumed to explode at the centre right inside pipe. The explosion is represented by a pressure load applied on the circumference of a circle with radius whose center coincides with that of the explosive charge. The magnitude is 30MPa which decreases linearly to zero in a time interval of 0.025 second. The initial stress state before explosion was obtained in the first step and dynamic response under the blast loading was obtained using Dynamic Explicit during the second step analysis. In the whole work, fifteen (15) models were studied.

RESULTS AND DISCUSSIONS

It is worthy of mentioning here that the topmost part of the cross-section of the pipe is known as the ***crown*** while the base resting on the ground is known as the ***invert***. The two sides of the cross-section of the pipe is known as the ***spring-line*** as shown in Figure 1a. Subsequently, these terms will be reffered to in the following sections. From the result of this study, the pressure genertaed in three different diameter pipes for the three charge weights are graphically presented in Figs. 2(a & b). In addition, the response of soil around the pipes in three different depth of embeddements as well as the response of the pipes at three different depth of embeddements are presented in Figs. 3(a-d). Finally, owing to the capability of Abaqus Dynamic Explicit analysis, the energies generated and external work by the explosion of 50kg TNT considered in the buried steel and concrete pipes in different soil media graphically presented in Fig. 4.

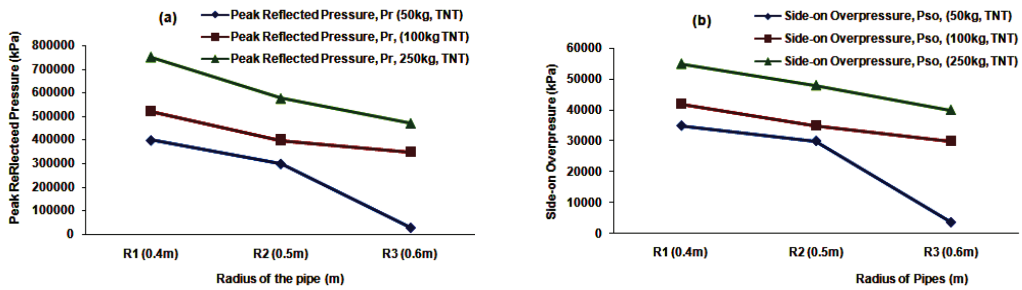


Figure 2. Pressure generated in different diameter pipes for the three charge weights: (a) peak reflected pressure; (b) side-on overpressure

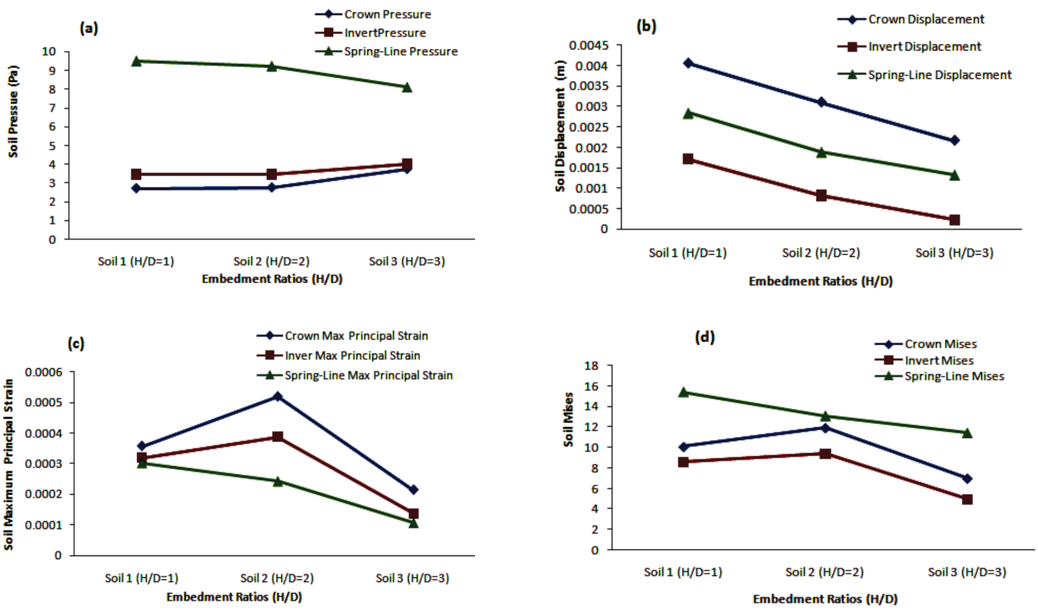
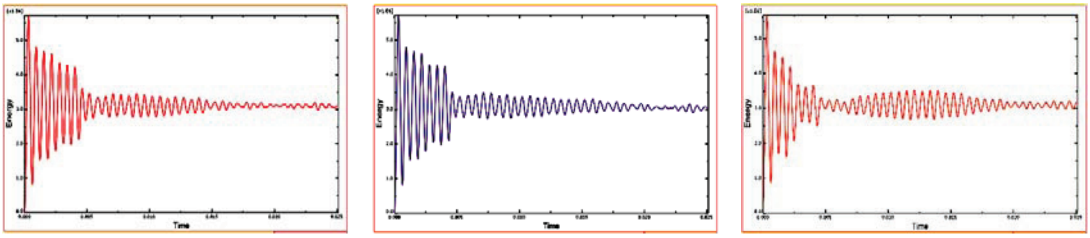
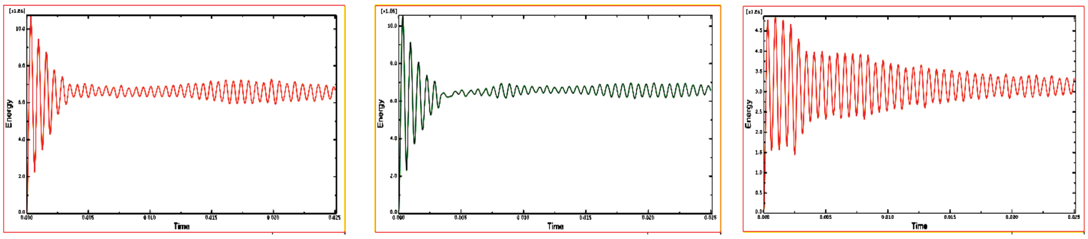


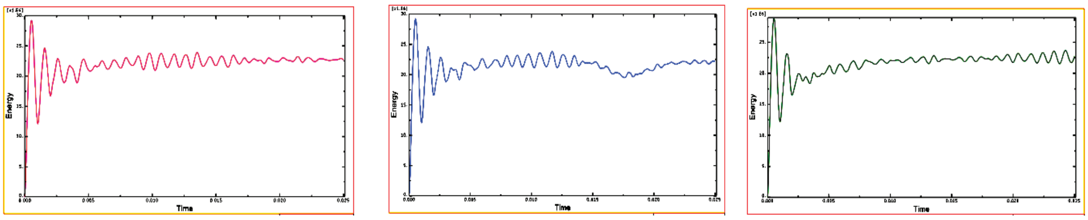
Figure 3. Effects of different depth of embedment on the soil around the pipe: (a) pressure; (b) displacement; (c) max principal strain (d) mises



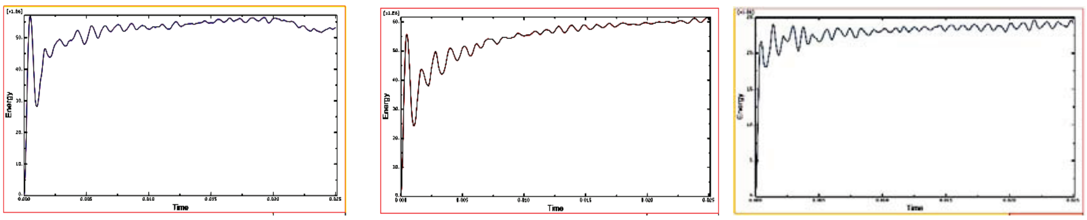
External work (N-m) against time (s) in 20mm steel pipes buried at 3.04m depth



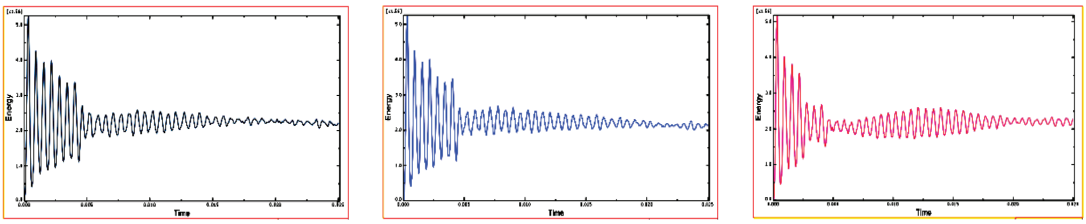
External work (N-m) against time (s) in 10mm steel pipes buried at (a) 3.04m, (b) 6.04m depth



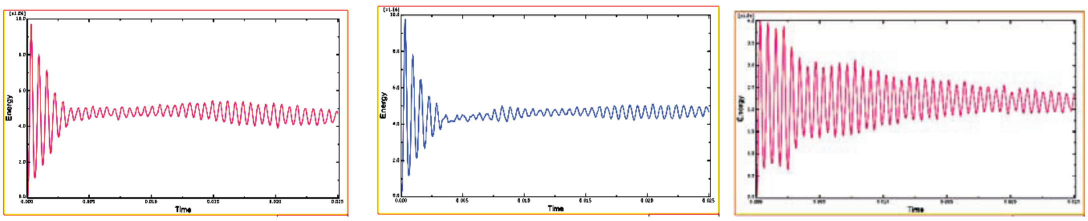
External work (N-m) against time (s) in 20mm concrete pipes buried at 3.04m depth



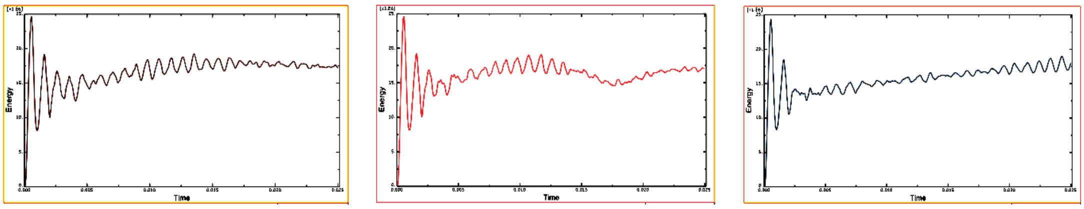
External work (N-m) against time (s) in 10mm concrete pipes buried at (a) 3.04m, (b) 6.04m depth



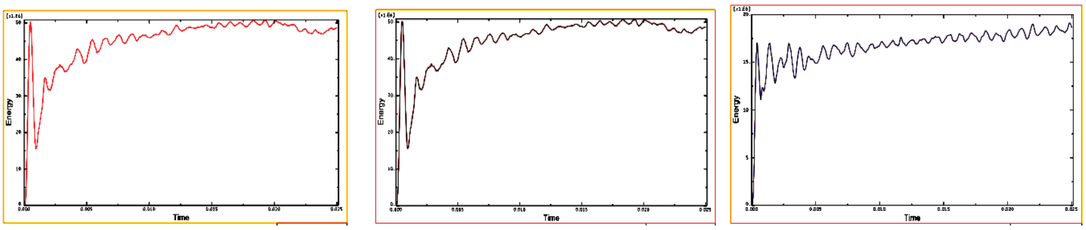
Internal energy (N-m) against time (s) in 20mm steel pipes at 3.04m depth



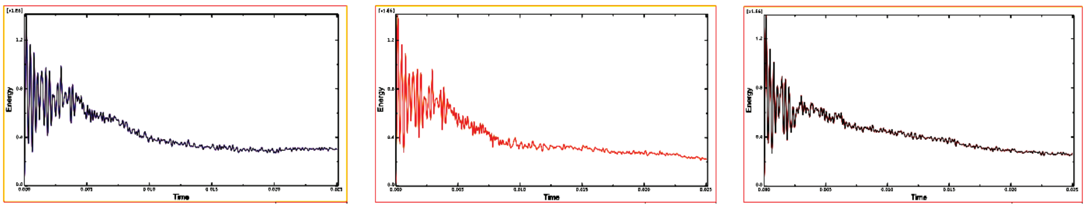
Internal energy (N-m) against time (s) in 10mm steel pipes at (a) 3.04m, (b) 6.04m depth



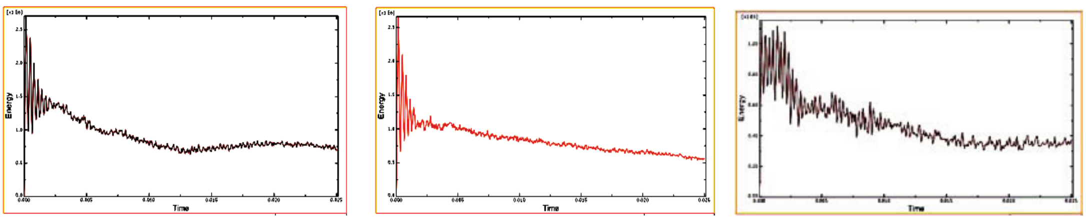
Internal energy (N-m) against time (s) in 20mm concrete pipes at 3.04m depth



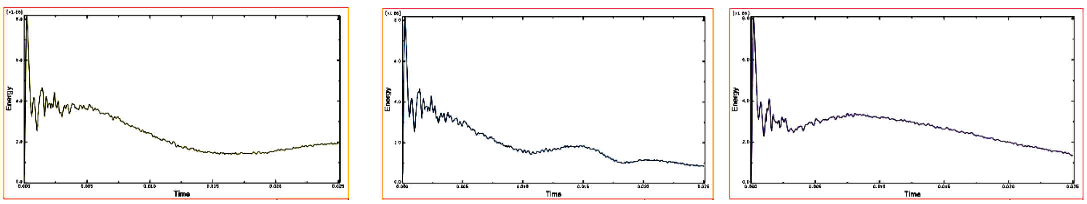
Internal energy (N-m) against time (s) in 10mm concrete pipes at (a) 3.04m, (b) 6.04m depth



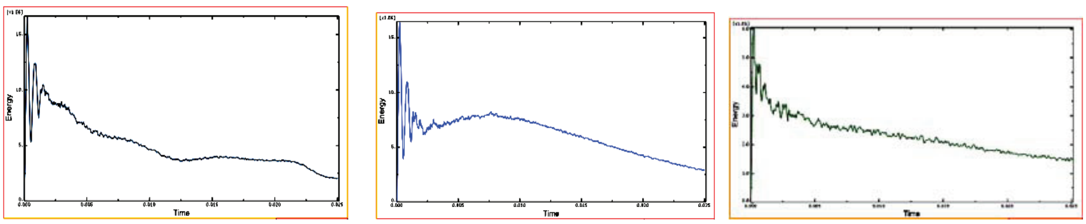
Kinetic energy (N-m) against time (s) in 20mm steel pipes buried at 3.04m depth



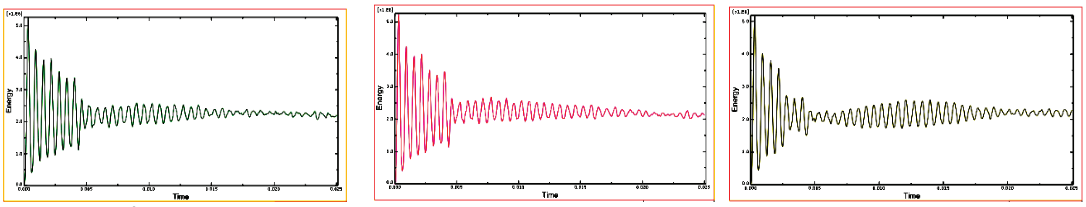
Kinetic energy (N-m) against time (s) in 10mm steel pipes buried at (a)3.04m, (b) 6.04m depth



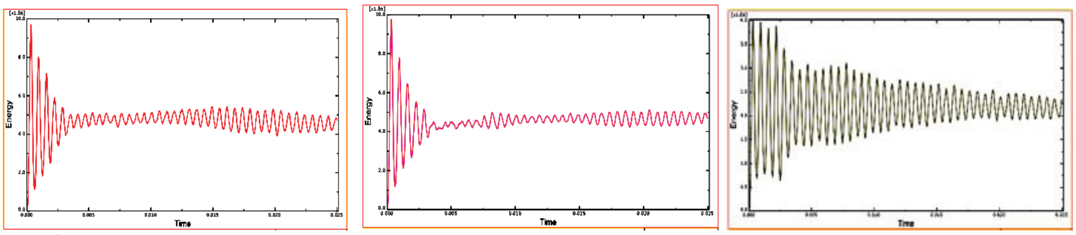
Kinetic energy (N-m) against time (s) in 20mm concrete pipes buried at 3.04m depth



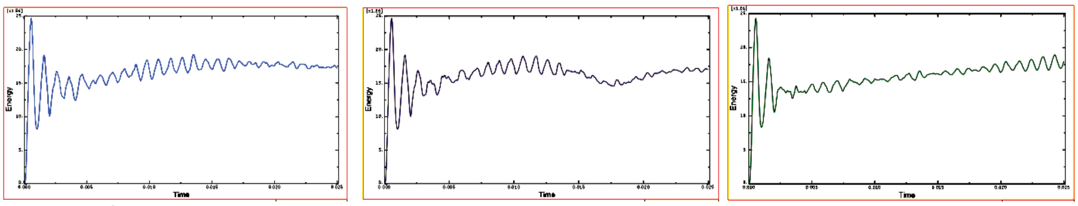
Kinetic energy (N-m) against time (s) in 10mm concrete pipes buried at (a) 3.04m, (b) 6.04m depth



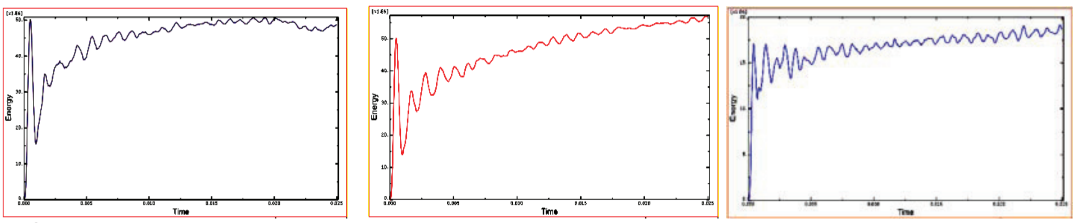
Strain energy (N-m) against time (s) in 20mm steel pipes buried at 3.04m depth



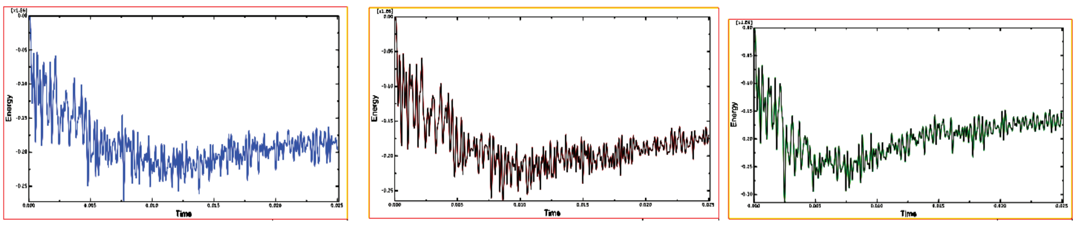
Strain energy (N-m) against time (s) in 10mm steel pipes buried at (a) 3.04m, (b) 6.04m depth



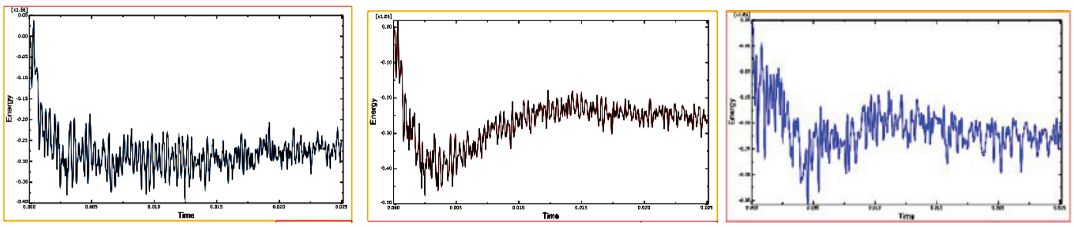
Strain energy (N-m) against time (s) in 20mm concrete pipes buried at 3.04m depth



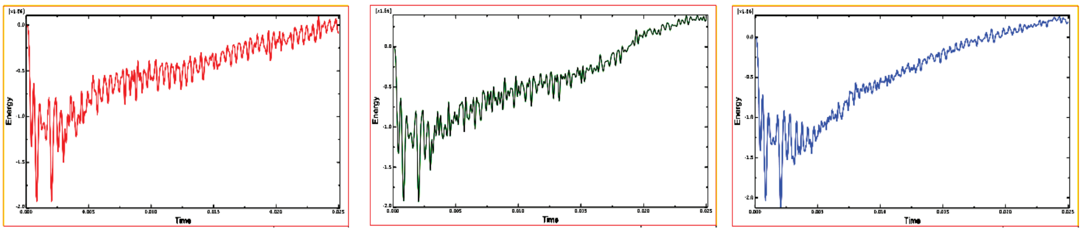
Strain energy (N-m) against time (s) in 10mm concrete pipes buried at (a) 3.04m, (b) 6.04m depth



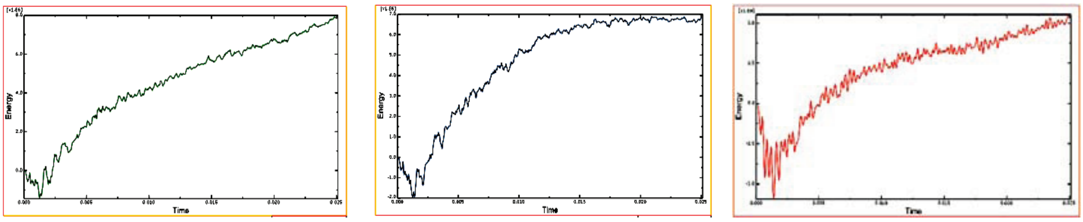
Total energy (N-m) against time (s) in 20mm steel pipes buried at 3.04m dept



Total energy (N-m) against time (s) in 10mm steel pipes buried at (a) 3.04m (b) 6.04m depth



Total energy (N-m) against time (s) in 20mm concrete pipes buried at 3.04m dept



Total energy (N-m) against time (s) in 10mm concrete pipes buried at (a) 3.04m, (b) 6.04m depth

Figure 4. External work and energy generated by 50kg TNT in steel and concrete pipes in different soil media

If a shock wave impinges on a structure (in this case, internal walls of pipes), a reflected pressure raised to a value higher than incident pressure is instantly developed as shown in Figs. 2(a-b). It could be seen from these figures that as the diameter of the pipe increases, peak reflected pressure and side-on overpressure reduces. The value of reflected pressure is higher than that of side-on overpressure for each of the diameter of pipes considered. This indicates that for a given explosive, higher pressure is expected to take place in pipes of smaller diameter. This agrees with the results and submissions of Remennikov (2003), Bibiana et al. (2008) and Ngo et al. (2007) that pressure decays as the distance from the point of explosion increases. It has been observed that an increase in rigidity (stiffness) of underground structures causes an increase in the peak pressure. A very stiff structure behaves like a rigid solid block in the soil medium. Under the impact of surface static pressure loading using Abaqus Standard, at H/D = 1, for no slip condition, the spring-line of the pipe has the highest pressure and mises values while the crown and the invert has the least values of the same parameters. It shows that as the spring-line is bulging out as a result of the overburden and static pressures, it compresses the soil and soil itself is excerting pressure on it. This interactions result in increase in the values of the above mentioed parameters.

The crown pressure at H/D=1 is 0.99 (approximately 1.0) times that of crown pressure at H/D=2 and it further reduces to 0.74 times that of crown pressure at H/D=3.The crown mises at H/D=1 is 0.844 times that of the crown mises at H/D=2, while the crown maximum prinicipal strain at H/D=1 is 0.688 times that of the crown maximum principal strain at H/D=2. In addition to this, the crown has the highest displacement while the invert has the least. This value reduces as the depth of embedment increases as shown in Figures 3(a-d). This is due to the effects of overburden pressure and that of static load resting directly on it. The crown displacement at H/D=1 is 1.307 times that of crown displacement at H/D=2. The maximum horizontal sprig-line response in terms of pressure, displacement, maximum principal strain and mises for H/D=1 is 1.2385 times that of maximum horizontal spring-line response for H/D=2. This is in line with the submissions of Roanaki (1997) that

*"Embedment depth has significant effect on both the crown and spring-line response. With increase of depth of embedment of pipes, the response decreases. The maximum crown response for H/D=1 is about 1.3 times that of the maximum crown response of H/D=2. In case of spring-line response, the maximum horizontal spring-line deflection for H/D=1 is about 1.2 times that of maximum horizontal spring-line deflection of H/D=2".*This validate the existing model studied by Ronanki (1997) using SAP program.

From the results of the study on internal explosion, steel pipes of 20mm thick, 1.0m diameter buried at 3.04m depth in loose sand, dense sand and undrained clay have similar maximum values of external work (5.64 x 10^6 N-m at 0.000334s), internal energy (5.24 x 10^6 N-m at 0.000334s), kinetic energy (1.41 x 10^6 N-m at 0.000334s), strain energy (5.24 x 10^6 N-m at 0.000334s) and total energy (-1.81 x 10^5 N-m at 0.000552s). On the other hand, concrete pipes of the same diameter and thickness buried at the same depth in different soil media as stated above have similar maximum values of external work (2.92 x 107 N-m at 0.000396s), internal energy (2.46 x 10^7 N-m at 0.000427s), kinetic energy (8.15 x 10^6 N-m at 0.000151s), strain energy (2.46 x10^7 N-m at 0.000427s) and total energy (-2.03 x 10^6 N-m at 0.000646s). Similarly, steel pipes of 10mm thick, 1.0m diameter buried at 3.04m depth in loose sand, dense sand and undrained clay have similar maximum values of external work (1.07 x10^7 N-m at 0.000332s), internal energy (5.02 x 10^7 N-m at 0.000393s), kinetic energy (2.70 x10^6 N-m at 0.000152s), strain energy (9.77 x 10^6 N-m at 0.000332s) and total energy (-3.24 x 10^5 at 0.000824s).

On the other hand, concrete pipes of the same diameter and thickness buried at the same depth and in different soil media, have similar maximum values of external work (5.57 x 10^7 N-m at 0.000378s), internal energy (5.03 x 10^7 N-m at 0.000393s), kinetic energy (1.66 x 10^7 N-m at 0.000167s), strain energy (5.03 x 10^7 N-m at 0.000393s) and total energy (-1.95 x 10^6 N-m at 0.001116s). Increasing the depth of embedment to 6.04m, steel pipe of 20mm thick and 1.0m diameter buried in the same soil medium have maximum values of external work (4.84 x 10^6 N-m at 0.000955s), internal energy (4.0 x10^6 N-m at 0.000338s), kinetic energy (1.12 x 10^6 N-m at 0.001448s), strain energy (4.0 x 10^6 N-m at 0.000338s) and total energy (-2.7 x 10^5 N-m at 0.001047s). Finally, concrete pipe of the same parameters buried in the same soil medium at the same depth have maximum values of external work (2.40 x 10^7 N-m at 0.001047s), internal energy (1.70 x 10^7 N-m at 0.001078s), kinetic energy (6.03 x 10^6 N-m at 0.0-000185s), strain energy (1.70 x 10^7 N-m at 0.000338s) and total energy (-1.18 x 10^6 N-m at 0.001078s). The minimum values of all these parameters are shown in Figs. 4.

From these results, as shown in Figs. 4, the external work and energies rises to the maximum values after which it reduces to an almost constant values through out the time period considered. This shows clearly that, irrespective of the materials, the behavior of wave energies due to explosion in an empty underground pipe is different compared to surface blast. This is because the pressures is reflected from the internal surface of the empty pipe and later converge at the centre point of the explosion after which the residual wave energies travel back and impinges on the internal surface of the pipe. This process continues until equilibrium is reached when a constant and stable value is maintained through out the time period considered. This residual energy is higher in concrete pipes than steel pipes (Fig. 4). Simply put, the initial behavior could be thought of as sinusoidal wave before stabilizing to a constant external work and energies. In addition, the external work as a result of explosion is the same in 20mm thick steel pipes embedded in loose sand, dense sand and undrained clay while at the same depth of embedment, it is higher in 20mm thick concrete pipe buried in the same loose sand, dense sand and undrained clay as shown in Fig. 4. In addition to this, the internal energy, total energy, strain energy and kinetic energy generated is similar but lower in the 20mm thick steel pipes buried in the same loose sand, dense sand and undrained clay while these parameters are higher in the same diameter concrete pipes buried in the same soil media as shown in Figs. 4. This means that steel pipe material and the thickness considered has higher stiffness to absorb the wave propagated as a result of the explosion compared to concrete pipe material of the same thickness. Furthermore, at the same depth of burial, as the thickness of both the steel and concrete pipes reduces, internal energy, total energy, strain energy, kinetic energy and work done increases in the same proportion with the geotechnical properties of soil media showing no significant consequences as shown in Figs. 4. This justifies the non-inclusion of intervening medium in the analysis. However, stress components and equivalent earthquake parameters on the ground surface reduce as the depth of embedment increases. These equivalent earthquake parameters are higher than those recorded in San Fernando earthquake of 1971 (Robert, 2002). Finally, using the same diameter and thickness of pipes, increasing the depth of burial showed no significant changes in the internal energy, total energy, strain energy, kinetic energy and external work of steel and concrete pipes. It has been shown that the depth of explosive charge has no significant effect on the free-field pressure as long as the charge location is not too shallow. A change in pressure occurs when the compressive wave come in contact with a buried structure (Zhengwen, 1997).

CONCLUSIONS

This study has established that as the diameter of pipe increases, peak reflected pressure and side-on overpressure as a result of explosion in pipes reduce. Under static loading, at H/d=2, the values of pressure, displacement, mises and strain in the pipe reduced to zero beyond which no significant response occurred. Unlike concrete pipes, due to higher stiffness, steel pipe has the capacity to absorb most of the energies generated as a result of the explosion. In addition, it is evident that as the thickness of steel and concrete pipes reduces, external work and energies generated as a result of the explosion increases in the same proportion. Increasing the depth of burial of pipes showed no significant changes in the external work and energies generated. Furthermore, geotechnical properties of the soil medium has no significant consequence on the external work and energy generated as a result of the explosion inside the pipe, but stress components on ground surface reduces as the depth of embedment increases. Consequently, equivalent earthquake parameters on the ground surface as a result of blast in buried pipes are higher than those recorded in San Fernando earthquake of 1971. Lastly if underground pipe is to be designed to resist the effects of internal blast from explosives and it is to be laid in any soil medium at H/D not greater than 1, it is hereby suggested that steel pipes of minimum thickness of 20mm be used. This thickness will absorb most of the energies generated by explosive up to around 50kg TNT or equivalent. Other numerical codes like ANSYS, AUTODYN (2D and 3D), FLAC 2000, etc could suitably be used to study the response of underground structures due to blast load.

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OPTIMISATION OF CONCRETE MIX DESIGN USING SANDSTONE REACTIVE AGGREGATE IN SABAH

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Abstract
Concrete structure is significant for civilization because it is main constituent of human shelter. But it may destroy by map crack which caused by Alkali Silica Reaction (ASR). The presence of reactive aggregates, high alkaline pore solution and high moisture level in concrete are the sources of ASR. This study is aimed to develop the optimum concrete mix design to reduce the ASR of the sandstone aggregate quarries located in Sabah. The Clay Brick Powder (CBP) used as a cement replacement material in the proportion of 5 % to 25 % in this study. The test includes Accelerated Mortar Bar Test (AMBT) and autoclave expansion test for mortar bar expansion and compressive strength of mortar cubes for sandstone of five samples and control sample of granite aggregates. It was observed from AMBT, the mortar bar expansion of all sandstone aggregate samples is higher than 0.10 %. Hence, the entire sample tested is harmful degree of reactivity. The AMBT and autoclave expansion test shows that the clay brick powder has a potential to be used as a cement replacement materials to reduce the harmful reactivity of the sandstone. As the percentage of the clay brick powder increases, the reactivity of the sandstones decreases. The optimum mix design to reduce reactivity and to satisfy the compressive strength of concrete for structure use was found to be at 15 % cement replaced by CBP.

Keywords: *Sandstone Reactive Aggregate, Optimum Mix Design, Clay Brick Powder, AMBT, Autoclave Curing, Compressive Strength*

INTRODUCTION

Concrete is probably the most versatile material used in the construction industry. The aggregate fraction of concrete is often thought of as an essentially inert filler material, extending the active cement paste to more economic volumes. Reactive components may be found in different components of the aggregates such as igneous, sedimentary, or metamorphic components. A wide variety of aggregate types in common use across Malaysia, particularly those with a siliceous composition such as sandstone aggregate abundantly available and used in Sabah, East Malaysia. Many siliceous rock types are known to be reactive and will cause Alkali Silica Reaction in concrete. Alkali-Silica Reaction (ASR) is a chemical reaction between the alkalis in cement and certain siliceous aggregates and forms a silica gel. So long as the internal relative humidity of concrete exceeds 80 percent, the gel absorbs water and swells damaging the concrete (García-Lodeiro et al. 2007). The first case of ASR was reported to occur in Malaysia in 1986 at the pile head of Sg. Pontian in Rompin (Ng et al. 2011). The ASR problem in Malaysia was been highlighted in March 1988 when the Singapore Government banned the import of volcanic quarry stones from the Pengerang area in Johor (Chow and Abdul Majid Sahat, 1990). Another problem was found in 1989, when reinforced concrete bridge in east Johor was deteriorated mainly due to ASR (Razak and Powzie, 1989). In 2004-2006, a few suspect ASR cases occurred in Sabah bridges, such as Tamparuli Bridge and Datuk Salleh Sulong Bridge (Ng et al. 2011). The effect of ASR can cause serious expansion and cracking in concrete, resulting in major structural problems and sometimes necessitating demolition.

It was reported that the annual production of sandstone aggregates in Sabah is about 6.5 million tones, which is more than 54% of the total annual stone production (Suresh 2006). Due to limited types and sources of aggregate, and with the huge amount of sandstone production, the use of sandstone aggregate is almost of the all construction projects in Sabah. The quick chemical test shows that the sandstone aggregate from Kota Kinabalu, Sabah are potentially reactive (Hamza et al. 2010). Deterioration of concrete structures because of ASR is causing increasing concern in almost all construction works locally in Sabah, both because of the potential threat to the service life of concrete structures and extra costs in specifying concrete to resist. Therefore, to increase the sustainable of concrete structure, it is imperative to take efficient measures to control or minimize the ASR occurrence in concrete containing reactive aggregate.

The uses of Supplementary Cementing Materials (SCM) such as silica fume, fly ash, slag and natural pozzolans and lithium admixtures are probably one of the most efficient means of controlling ASR in concrete. However, the efficiency of SCM in suppressing ASR in concrete may vary widely, and depends on factors such as the nature and the composition of the materials and the reactivity level of the aggregates. It is possible to obtain pozzolanic materials when clays are thermally treated (Ramachandran 1995). Thermally treated kaolinite clays have shown good performance in suppressing the expansion caused by the ASR (Ramlochan et al. 2000).

In a research study, it was shown that the optimum clay firing temperature to give maximum pozzolanic activity is around 1000ºC (Wild et al. 1997). Thus, it is possible to obtain a pozzolanic material when clay bricks are ground to adequate fineness. It was found that clay brick powder (CBP) not only refines the pore structure but also increases the resistance to various chemical attacks (O'Farrell et al. 1999). A comparative study on the effect of clay brick powder and class F fly ash on the alkali-silica reaction (ASR) of the mortar was evaluated. In this study, it was demonstrated that the finely ground waste clay brick has high potential to reduce the ASR expansion as well as the ASR-associated strength loss (Bektas et al., 2007). As the level of CBP replacement increases, the ASR expansions decrease (Turanli et al. 2003). The optimum dosage of pozzolonic materials such as CBP to be added into concrete may differ to each other due to its different properties. The objectives of this paper are to report the experimental investigation on the reactive level of sandstone aggregate from Sabah quarries and the optimum CBP used to minimize the ASR in concrete.

MATERIALS

Aggregates samples

The locally used granite and sandstone aggregate were used in this research. Sandstones are mainly found in most areas around Papar, Inanam, Menggatal, Telipok and Tamparuli. The stone reserves are between 100,000 and 2,000,000 m^3. Whereas, one of the granodiorite stock was found at Kampung Kapa, near Tamparuli, and is the nearest igneous stone area to Kota Kinabalu, which has been quarried for the past 15 years. In this study samples of about five types of sandstone aggregate and two types of granite aggregate were collected from different quarries nearby Kota Kinabalu. The details of sources, types and extraction methods of the sandstone and granite samples are tabulated in Table 1. The shape and size of all the samples are shown in Figure 1.

Table 1. Details of the aggregate samples

No.	Sample	Types	Location	Methods
1.	G1	Granite	Tamparuli-Ranau	Drill
2.	G2	Granite	Tamparuli-Ranau	Demolition
3.	S1	Sandstones	Kampung Keliangau-Menggatal	Demolition
4.	S2	Sandstones	Kampung Keliangau -Menggatal	Drill
5.	S3	Sandstones	Kampung Tampulan,Telipok	Drill
6.	S4	Sandstones	Kimanis, Papar	Drill
7.	S5	Sandstones	Kampung Benoni, Papar	Drill

Figure 1. Aggregate samples collected from different quarries nearby Kota Kinabalu, Sabah

TESTING METHODS

The testing methods namely Accelerated Mortar Bar Test (ASTM C 1260) and Autoclaving test were used in this study. Accelerated Mortar Bar Test (AMBT) was shortened testing period of ASTM C 227 from one year to about 14 days and it has been proven to be fairly reliable (Thomas et al. 2005). AMBT is generally effective for the slow reactive aggregates or producing late expansion in reaction. Since the expanding of samples is already prepared with sodium hydroxide (NaOH) solution, alkali content of the cement is not an important factor to influence the expansion. Thus, the expansion can be effectively investigating the ASR potential of the reactive aggregate (Davraz and Gündüz 2007).

In order to determine the potential alkali-silica reactivity of aggregate more quickly and accurate, a new method namely autoclave method has been developed. It requires 24 hours to test the expansion of the mortar bar. However, due to lack of results used to compare with other tests, the reliability of this method is still needs to be verified (Kozlova et al. 2004). In addition, the optimum mix design of concrete was conducted to satisfy the compressive strength requirement. The mortar bar samples were prepared according to ASTM C109 and cured under full water curing for 7 and 28 days. After curing, the compressive strength test was commenced for all samples to obtain its strength value.

Preparation of the mortar bar samples

The aggregate samples collected from different quarries were crushed to meet the grading requirement are given in Table 2 and the grading size also illustrated in Figure 2. The mortar bar test samples were proportioned using 1 part of cement to 2.25 part of graded aggregate by mass a water-to-cement ratio equal to 0.47 by mass (Lu et al. 2006). The quantities of dry aggregates to be mixed at one batch of three mortar bar specimens (with size of 2.5cm x 2.5cm x 25cm) are 440 g cement and 990 g aggregate. For each types of the sandstone aggregate, six sets of the admixture proportion were prepared. These proportions are 0%, 5%, 10%, 15%, 20% and 25% by weight of cement. The granite aggregate was used as control samples in this study and therefore no admixture was added to it. Similarly, for compressive strength test of mortar, the proportion was 1 part of cement to 2.75 part of graded standard fine aggregate by weight, with a water-cement ratio of 0.485.

Table 2. Grading requirement of the samples

Sample	Passing through	Retained on	Mass,%
a	4.75mm (No.4)	2.36mm (No.8)	10
b	2.36mm(No.8)	1.18mm (No.16)	25
c	1.18mm(No.16)	600μm (No.30)	25
d	600μm (No.30)	300μm(No.50)	25
e	300μm (No.50)	150μm (No.100)	15

Figure 2. Grading sizes as followed by ASTM C1260

Accelerated mortar bar test (AMBT)

The AMBT test was carried out in accordance to ASTM C1260 (ASTM 2005). This test requires that the aggregate be crushed to a prescribed grade and that mortar bars (2.5 × 2.5 × 25 cm) be cast with an aggregate-to-cement ratio of 2.25 by mass, and a water-to-cement ratio equal to 0.47 (Lu et al. 2006). Three mortar prisms are required for each sample. The mortar prisms are cured for 24 hours in a moist cabinet at 21 ± 2°C to avoid it from condensation. After demoulded, the samples were immersed in water in a sealed storage container and then placed in an oven at 80±2 °C for 24 hours.

After this curing process, the original length of the specimens was measured. They are then immersed in a closed container of 1M sodium hydroxide solution maintained at 80±2 °C. The volume of the solution must be sufficient to ensure the bars were completely immersed in the container. Precaution was taken not to let the bars in contact with each other and with the sides of the container. This is to ensure a full access of solution into mortar bar. The specimens were removed periodically from the containers and measured before significant cooling can occur. The length change of the prisms is measured up to 14 days after casting.

According to ASTM C 1260 (ASTM C1260 2005), if the observed expansion exceeds 0.20 percent after 14 days after casting, the aggregate tested should be considered potentially reactive. If the expansion measured lies between 0.10 and 0.20 percent after 14 days after casting, additional testing, supplemental information, and field performance data should be evaluated. If the expansion measured is less than 0.10 percent after 14 days after casting, it is indicative of innocuous behavior in most cases.

Autoclave expansion testing

After casting, the mortar bar samples were stored in the moist space immediately and remained in the mould for 24 hours. After demoulded, the initial length of the mortar bar was then measured to the nearest 0.002 mm. The specimens were then placed in the autoclave for 24 hours. In the autoclave test, steam with a temperature of 123 ± 2°C and a steam pressure of 0.13-0.15 N/mm^2 maintains sufficient moisture to accelerate any potential ASR. The steam curing is achieved solely by water, which itself does not contribute to any chemical alteration of a given composition. The pressure and temperature were selected for the suggested screening ASR test based on prior experience with autoclave methods. Tests had shown that temperatures around 123°C prevent the condensation of water on the specimens' surfaces. The steam pressure of about 0.15 N/mm^2 is in the range of common home pressure cookers, which were used by some researchers previously to detect ASR (Grattan-Bellew 1997).

After 24 hours of autoclaving, the specimens were removed and then the samples were immediately immersed in the water bath followed by gradually cooling down to the room temperature. The change in length of the specimens was measured and recorded. The expansion result is the average of three measurements.

RESULT AND DISCUSSION

AMBT results

The length of the mortar bars were measured before, during and after the AMBT curing. The length of mortar bar before the curing is known as zero reading (initial reading). The difference between the initial reading of the samples and the effective measurement length in 0.002 mm sensitivity for each period is calculated. The evaluation of the reactivity potential according to American Standard for Testing of Materials (ASTM C1260 2005), is given in Table 3. The average expansions of the three samples for the control mortar bar samples using AMBT are given in Figure 3 (i).

The average expansion of different location sandstone aggregate mortar bars using AMBT are shown in Figure 3 (ii) to Figure 3 (vi). The degree of reactivity interpreted according to ASTM for the sandstone mortar bar with cement and cement replaced with CBP at 5 %, 10 %, 15 %, 20 % and 25 % of the cement mass is given in Table 4. It can be clear from the results that the granite aggregate and quartz sand used as control samples shows harmless degree of reactivity.

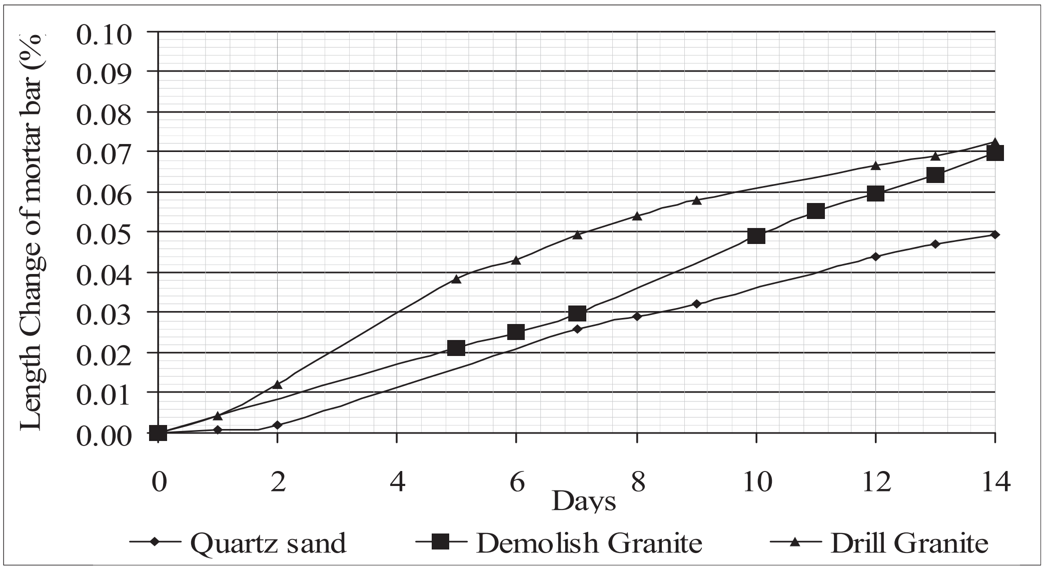

Figure 3(i). Length change of mortar bar for control samples (G1, G2)

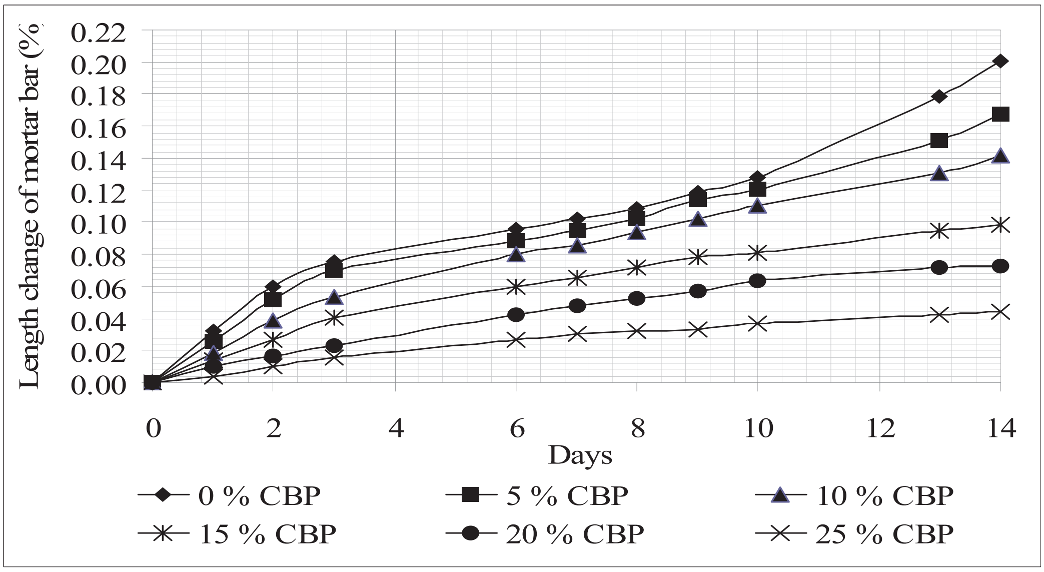

Figure 3(ii). Length change of Menggatal sandstone (demolish) mortar bar (S1)

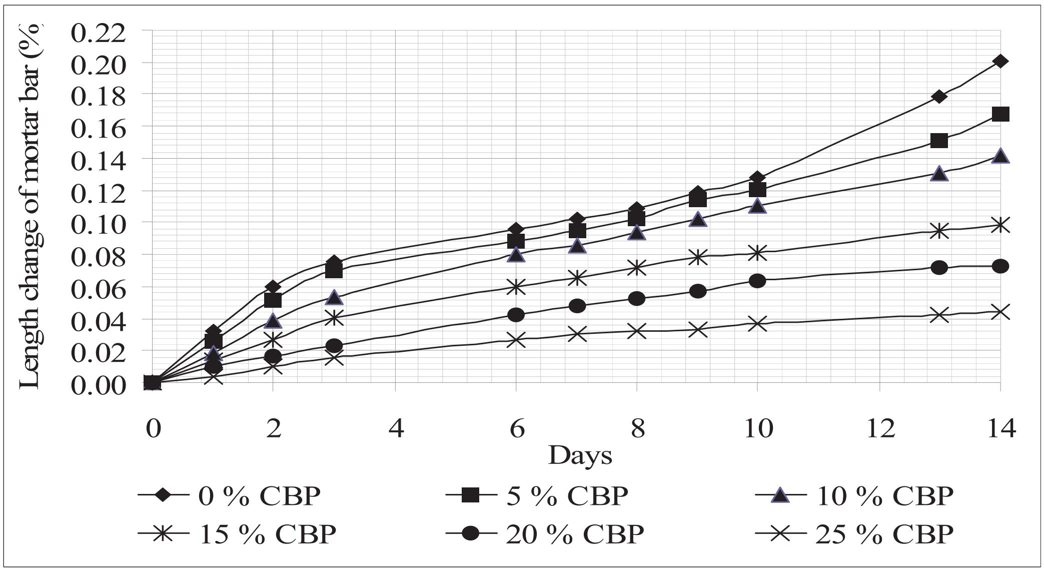

Figure 3(iii). Length change of Menggatal sandstone (drill) mortar bar (S2)

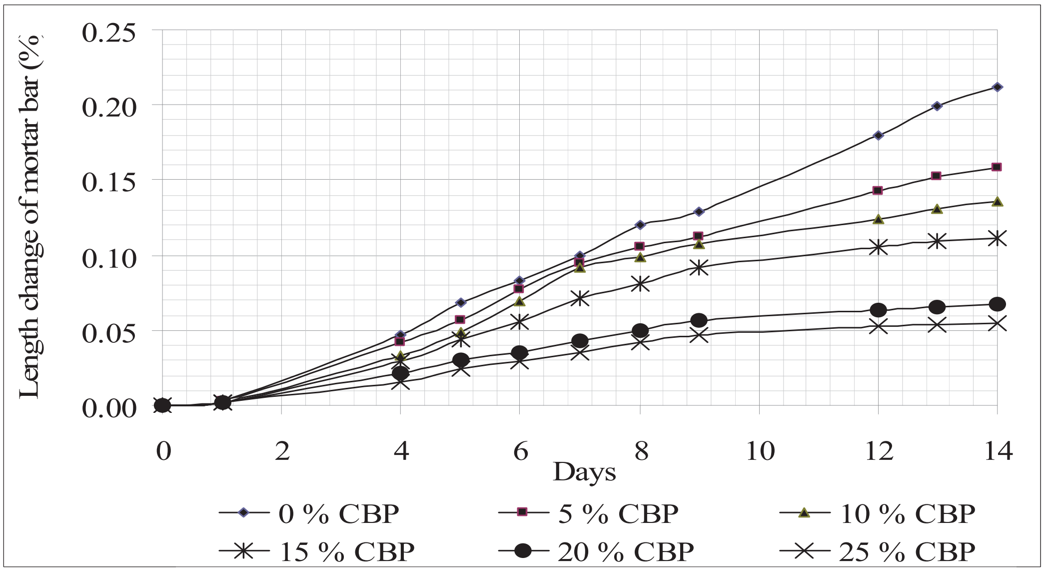

Figure 3 (iv). Length change of Telipok sandstone mortar bar (S3)

It was found that that the expansions of the samples S1. S2, and S3 are more than 0.20 % and it is considered as harmful degree of reactivity. The average expansion of the Papar samples S4 and S5 were found to be 0.18 % and it is referred as potential harmful degree of reacivity. In general, it is concluded that all the five location of sandstone quarries are considered as reactive aggregate. However, the CBP was added to these samples, the degree of reacivity was decreased. This indicats that the CBP is effective in reducing the ASR in concrete.

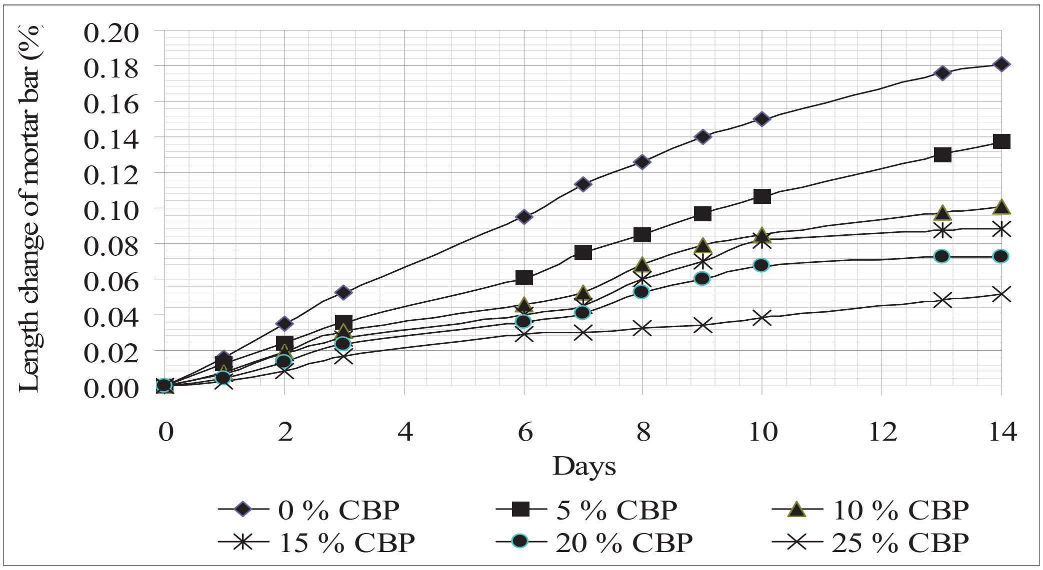

Figure 3 (v). Length change of Papar (Kimanis) sandstone mortar bar (S4)

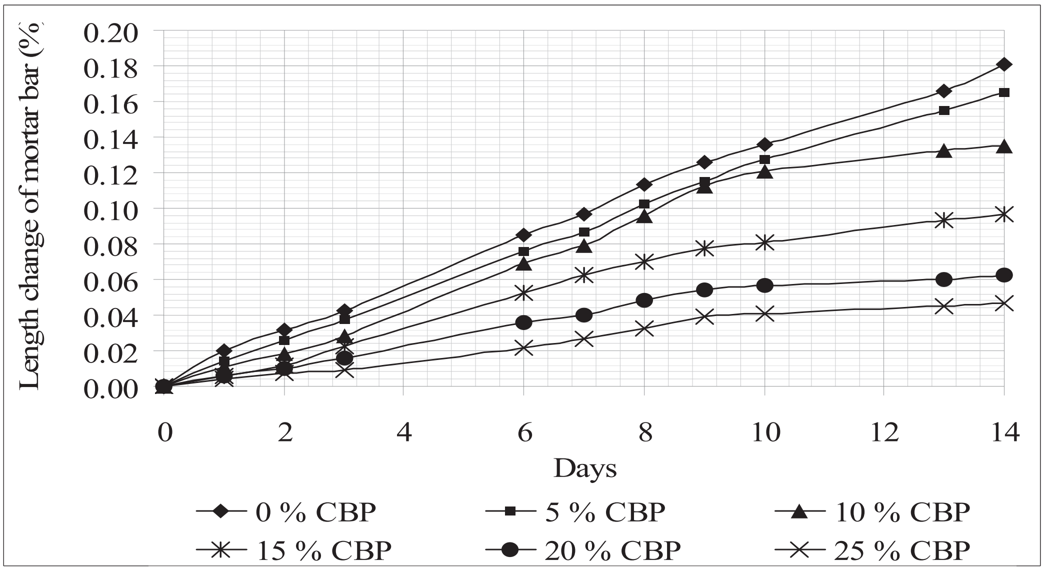

Figure 3 (vi). Length change of Kampung Benoni sandstone mortar bar (S5)

Table 3. Reactivity potential according ASTM

Expansion % at 16 days after casting	Degree of reactivity
Less than 0.10%	Harmless
More than 0.20%	Harmful
Between 0.10% to 0.20%	Potential Harmful

It was noticed that for the replacement of 15 % cement by CBP for the samples S2,S4 and S5, the degree of reactivity changed from potential harmful to harmless. But for the samples S1 and S3 are remaining as potential harmful. However, the expansion for these two samples at 15% CBP are 0.113% and 0.1059% respecitvely which are very close to harmless. All the samples shows harmless degree of reactivity at 20% and 25% CBP. The test results indicated that the expansions is decearsed as the precntage of CBP is incerased. CBP, it can be seen that the expansion of all mortar bars are decreasing. This trend is similar with the research done by Turanli et al. (2003) where the AMBT result shows decrease in expansion when CBP used as cement replacement. Based on this research, the optimum percentage of CBP to reduce the ASR can be adopted as 25 %. However, this experiment result was only based on ASTM C1260 (2005). This result may need acknowledge of other test to affirm its accuracy.

Table 4. Potential reactivity of the sandstone based on the AMBT Results

Sample	Percentage of CBP as cement replacement (%)					
	0	5	10	15	20	25
S1	Harmful	Potential Harmful	Potential Harmful	Potential Harmful	Harmless	Harmless
S2	Harmful	Potential Harmful	Potential Harmful	Harmless	Harmless	Harmless
S3	Harmful	Potential Harmful	Potential Harmful	Potential Harmful	Harmless	Harmless
S4	Potential Harmful	Potential Harmful	Potential Harmful	Harmless	Harmless	Harmless
S5	Potential Harmful	Potential Harmful	Potential Harmful	Harmless	Harmless	Harmless

Autoclave expansion test results

In autoclave expansion test, the change in length of mortar bar was measured before and after the autoclave curing. The average expansion of the three samples was considered as the expansion of the given sample. There is no standard guideline developed in this test to evaluate the degree of reactivity of the aggregate as compared with AMBT. However, this test results can be used to evaluate the trend of expansion for the mortar bar samples with different proportion of CBP. The autoclave expansion test for the control and different sandstone quarry samples with and without CBP are shown in Figure 4.

It was found that the autoclave expansion of the different quarry samples of sandstone aggregate were in the range of 0.02257 to 0.02469. Among the sandstone aggregate the lower expansion was observed in the sample S3. However, the cement replaced by CBP in the proportions from 5 % to 25 % the expansion decreased gradually. The simliar trend was observed in AMBT also. The results firmly affirm that the expansion of mortar bar with CBP was decreased either tested in AMBT or in autoclave expansion test.

It was observed that the tested samples did not exhibited any shrinkage. This observation is different from other studies. This may due to the difference of cement replacement material being used in the study. The results obtained by Kozlva et al.(2004) shows that the maximum length change after autoclave test was about 0.03 %. However, in this study the maximum length change for different quarry sandstone after autoclave curing was observed around 0.025 %. Therefore, regardless the effect of the cement replacement material, the result obtained was on the same trend compared with other studies (Kozlva et al 2004, Suresh 2006).

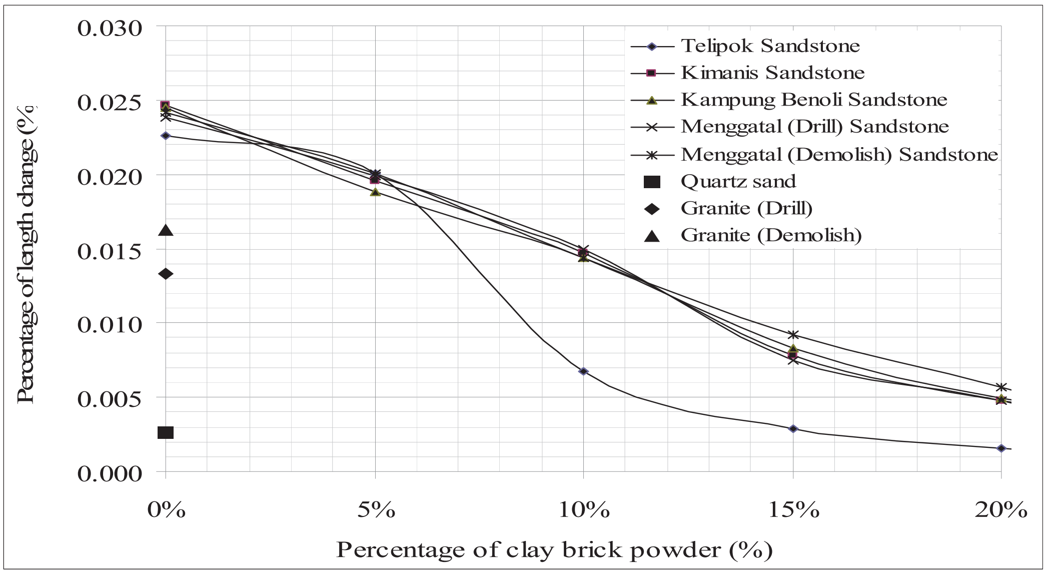

Figure 4. Autoclave expansion result of control and sandstone aggregate samples

Even though the autoclave test does not provide any standard criteria for the degree of reactivty, but the results shows that 25 % of CBP is the optimum proportion to decrease the reactivity of the sandstone aggregate. However, the development of optimum mix design to reduce the ASR of aggregate cannot be obtained by looking only the percentage of the CBP with less expansion of the concrete alone. The compressive strength of concrete also considered as an essential parameter to develop the optimum mix design.

Compressive strength of mortar

The 28-day compressive strength of sandstone aggregate mortar cubes with and without CBP is shown in Figure 5. Since this study was aimed to develop the optimum mix proportion to reduce the ASR, it is worthless to observe the compressive strength of the mortar cube alone. Thus, the relationships between the compressive strength and the expansion percentage base on AMBT have been developed and shown in Figure 6.

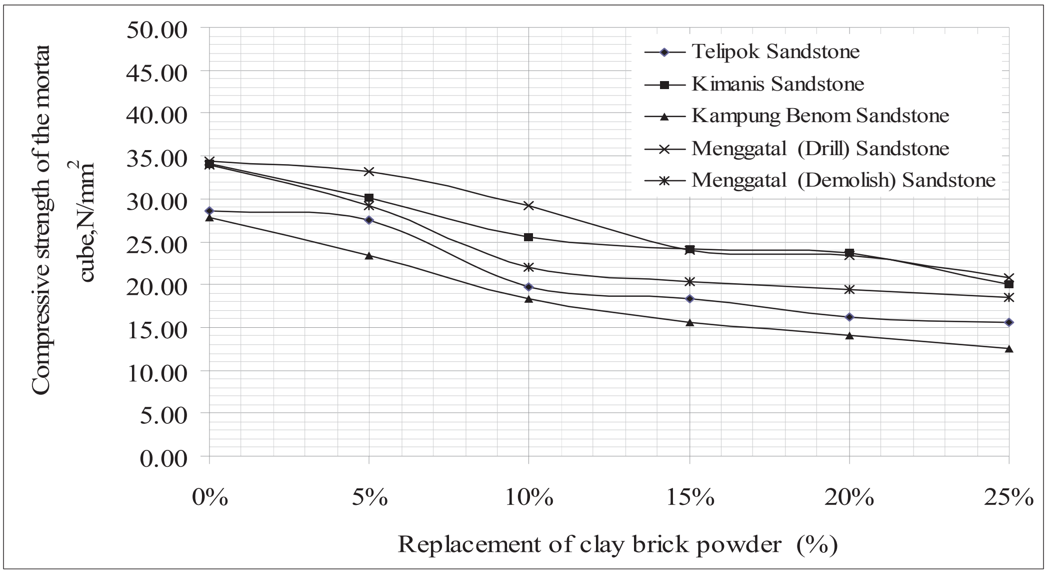

Figure 5. Compressive strength of sandstone aggregate mortar cube

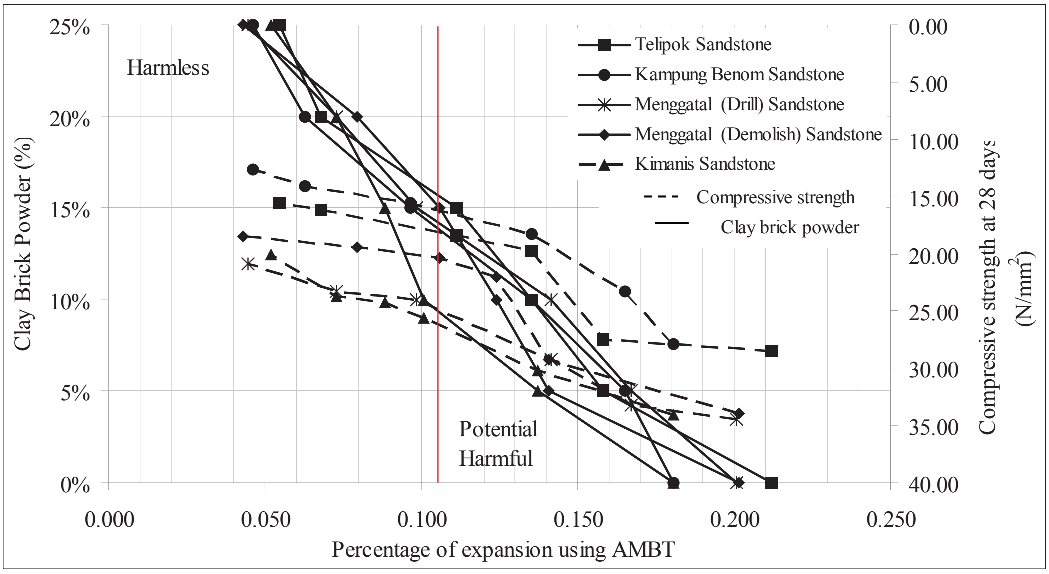

Figure 6. Expansion percentage Vs compressive strength of sandstone aggregate samples

All the samples results falling on the left side of the line (less than 0.1% expansion) is categorized as a harmless ASR zone. It was found that the compressive strength of the sandstone samples S1, S2 and S4 was 20.3 N/mm^2, 24.1 N/mm^2, and 25.5 N/mm^2 at 15% cement replaced by CBP. This result indicates that the sandstone quarries samples of S1, S2 and S4 were closely harmless reactivity and satisfy the compressive strength requirements for structural use at 15% cement replaced by CBP. This trend is similar to the other studies (Bektas et al. 2007 & 2008). Although the compressive strength of Telipok sandstone sample (S3) satisfies but it falls under potential harmful category. This may be due to the higher amount of reactive silica presents in the aggregate. The compressive strength and the expansion for the sample S5 was observed 15.6 N/mm^2 and 0.0967 % respectively. The lowest compressive strength at 15% cement replaced by CBP may be due to the porosity of the sandstone aggregate (Suresh, 2006). It is reasonably concluded that the potential reactivity of given sandstone samples are greatly reduced by the replacement of CBP in the range of 15 % to 20 %. However, further studies on different cement replacement are needed to confirm the above statement.

CONCLUSION

The following conclusion can be made on the basis of experimental results:

1. It was observed from AMBT, the mortar bar expansion of all sandstone aggregate samples is higher than 0.10 %. Hence, the entire sample tested is harmful degree of reactivity.
2. The AMBT and autoclave expansion tests show that the clay brick powder has a potential to be used as a cement replacement materials to reduce the reactivity of the sandstone. As the percentage of the clay brick powder increases, the reactivity of the sandstones decreases.
3. The optimum mix design to reduce reactivity and to satisfy the compressive strength of concrete for structure use was found to be at 15 % cement replaced by CBP.

ACKNOWLEDGEMENT

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PRECAST C-CHANNEL FLOOR FOR RURAL AND ESTATE HOUSINGS

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Abstract
Rapid urbanisation due to exponential growth of population in the world today has significantly resulted in housing demand. Adversely, the annual worldwide concrete usage standing at 2.7 billion m^3 has caused serious depletion of non-renewable natural stones used in concrete production. In Sabah, Malaysia alone, the annual usage of non-renewable construction aggregates have reached about 12 million tons. It therefore becomes crucial to explore the alternatives of renewable resource particularly the Oil Palm Shell (OPS) solid waste, a by-product from the agricultural sector. Malaysia being the largest palm oil producer in the world has produced more than 4 million tons of OPS annually. The use of OPS as coarse aggregates in concrete production known as OPS concrete has been recommended as structural lightweight concrete (LWC). Due to the low modulus of elasticity of OPS concrete, conventional crushed granite was added to OPS concrete mix to produce concrete known as OPS hybrid concrete chiefly used in precast flooring slabs fabrication. In line with Industrialised Building System (IBS), precast floor system has been known for its many advantages over the cast in-situ concrete slab. This paper discusses the behaviour of precast C-channel floor of 3, 4, 5, 6, 7, and 8 m span subjected to Uniformly Distributed Loading (UDL). Under UDL, the corresponding load capacity of C-channel of varying spans reduced as the span increased. The deflection recovery of C-channels has satisfied the requirement based on National Building Code of India. This has proved that the C-channels of 3, 4, 5, 6, 7 and 8 m span can be fabricated using OPS hybrid concrete with minimum compressive strength of 22 MPa.

Keywords: *C-channel; Deflection Recovery; Oil Palm Shell (OPS); Precast Floor; Uniformly Distributed Loading (UDL)*

INTRODUCTION

Rapid urbanisation due to exponential growth of population in the world today has significantly resulted in housing demand. Adversely, the annual worldwide concrete usage standing at 2.7 billion m^3 has caused serious depletion of non-renewable natural stones used in concrete production. In Sabah, Malaysia alone, the annual usage of non-renewable construction aggregates have reached about 12 million tons. It must be noted that nearly 80% of the resources used today are non-renewable. Due to the scarcity of conventional raw materials, there is a great opportunity to explore the alternatives of renewable resource particularly the Oil Palm Shell (OPS) solid waste, a by-product from the agricultural sector. Malaysia being the largest palm oil producer in the world has produced more than 4 million tons of OPS annually, from which about 1.5 million tonnes is generated in Sabah (Teo, 2007). To combat the issue of solid waste disposal, OPS can be salvaged for more environmental friendly and commercial viable end particularly in the rural and estate housings.

Currently, Malaysia has become the largest palm oil producer in the world with a total number of palm oil mills reaching 417, of which 117 are in Sabah (Business Times, 26 January 2010). It must be noted that each palm oil estate needs housing for its staff of about

500 people from mill manager to workers. Various supports have been given under our Malaysian Government to sustain the growth of the palm oil industry in the years ahead.
The use of OPS as coarse aggregates to produce concrete known as OPS concrete has been recommended as structural lightweight concrete (LWC) (Olanipekun et al., 2006; Teo et al., 2007; Alengaram et al., 2008; Jumaat et al., 2008; Teo et al., 2010). Though OPS, being as agricultural solid waste, is biodegradable and is likely to decay under vigorous environments, its durability performance has been determined. Ramasamy *et al*. (2008) have investigated the performance of OPS and OPS concrete under aggressive conditions. They have revealed that OPS aggregates are durable under potable water, deleterious solutions such as salt and alkaline solutions of 3% sodium chloride (NaCl) and sodium hydroxide (NaOH with approximate 13 pH) respectively. As for OPS concrete, it is relatively durable in term of compressive strength when exposed to potable water and salt solution. Teo *et al*. (2010) have also investigated its durability properties such as the Volume of Permeable Voids (VPVs), sorptivity, water permeability, chloride diffusion coefficient and time to corrosion initiation from 90-day salt ponding test, and Rapid Chloride Penetrability Test (RCPT). It was found that the results compared reasonably well with other LWCs.

In a typical modern building made of reinforced concrete, the conventional concrete floor slab system consumes the highest concrete volume up to 44% compared to other structural components. The floor construction is the most time-consuming and costly activity particularly for a framed building, representing some 60%-80% of the total in both cost and time (Goodchild, 1997; Matthew and Bennett, 1990). The floor slabs can be made of in-situ reinforced concrete or precast concrete. In the present, there are many types of precast concrete floors available in the markets such as flat slab, rib and timber infill floor, hollowcore, single-T, double-T, beam and blocks, semi-precast slab, and channel slab. Each of these precast products has its own advantages and disadvantages. Generally, they are heavy in weight being made with Normal Weight Concrete (NWC), and also, they require cast in-situ concrete topping which increase the cost of overall production. Prestressed elements which require jacking system is very costly. Therefore, the proper selection of more efficient materials and improved design is essentially required to reduce the cost of precast floor production.

Also in line with IBS system, precast floor system particularly made with LWC has been known for its many advantages over the cast in-situ concrete slab. Lightweight concrete floor panels can allow speedy erection thus shorten the overall construction time. The erection procedure, and in turn the design of the structure is very much affected by the weight and size of the individual components.

This paper discusses the behaviour of six prototype precast reinforced concrete C-channels of 3, 4, 5, 6, 7, and 8 m span subjected to uniformly distributed loading (UDL). UDL is the most common type of distributed load, in which a load of constant magnitude is applied along a length of a beam or an area of a surface. Not only so, uniform load is considered adequate for design purpose (Reynolds and Steedman, 1992). In the design of slabs, in addition to self-weight a uniform imposed load is usually considered (Baskaran and Morley, 2004).

MATERIALS

The ordinary Portland cement of ASTM Type I, river sand, OPS and crushed granite have been used. The OPS aggregates have been obtained from Desa Talisai Palm Oil mill, IJM Plantations, Sandakan, Sabah. The properties of OPS, granite and river sand used in this study are shown in Table 1. Testing of aggregates is conducted as per relevant BS or ASTM. Table 2 shows the mix proportions of OPS hybrid concrete, as investigated by Ng et al. (2006, 2007). Free water/ cement (w/c) ratio is 0.38. OPS aggregate used is in saturated surface dry condition. Type-F naphthalene sulphonate formaldehyde condensed based super plasticizer in aqueous form conforming to ASTM C 494 has been used to increase the workability. The insight of OPS LWC, OPS hybrid LWC and NWC is shown in Figures 1, 2 and 3 respectively.

Table 1. Properties of OPS, crushed granite and river sand

Property of Aggregates	Unit	Coarse aggregate		Fine aggregate
		OPS	Granite	River sand
Maximum Size	mm	12.00	19.00	1.18
Specific Gravity (SSD)	~	1.34	2.63	2.43
Water Absorption Capacity (24 hrs)	%	21.30	2.04	3.89
Moisture Content as received	%	11.68	0.78	0.69
Los Angeles Abrasion Value	%	2.90	11.85	~
Bulk Density, compacted	kg/m^3	646	1481	~
Fineness Modulus	~	6.30	6.94	1.33
Aggregate Impact Value, AIV	%	6.60	12.60	~
Aggregate Crushing Value, ACV	%	7.12	15.95	~

Table 2. Constituents of 1.0 m^3 OPS hybrid concrete

Constituent	Unit	Quantity
Cement	kg	450
Water	kg	171
River Sand	kg	629
OPS	kg	341
Crushed granite	kg	313
Super plasticizer	liter	7.5

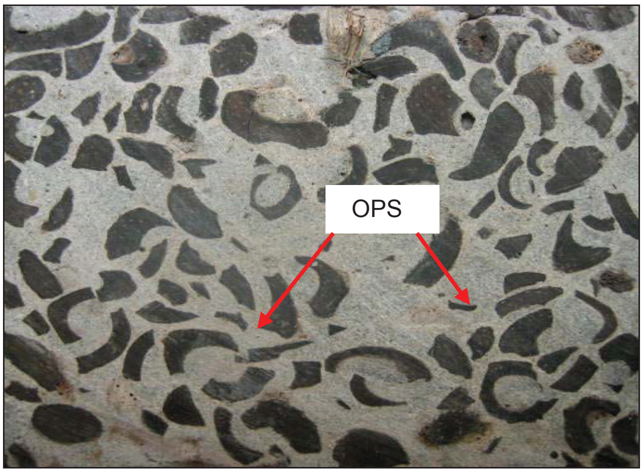

Figure 1. Insight of OPS LWC

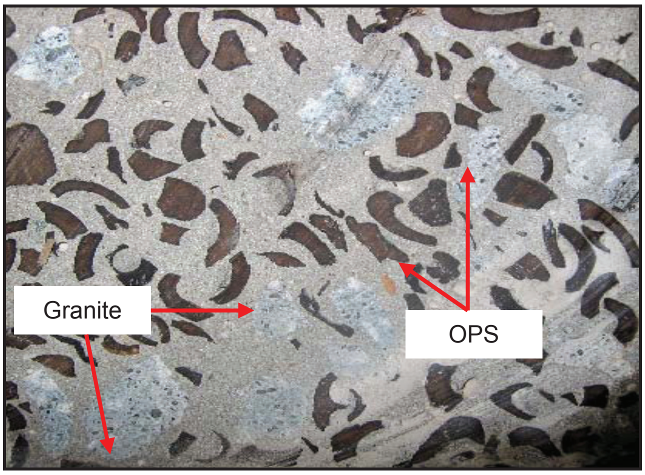

Figure 2. Insight of OPS hybrid concrete

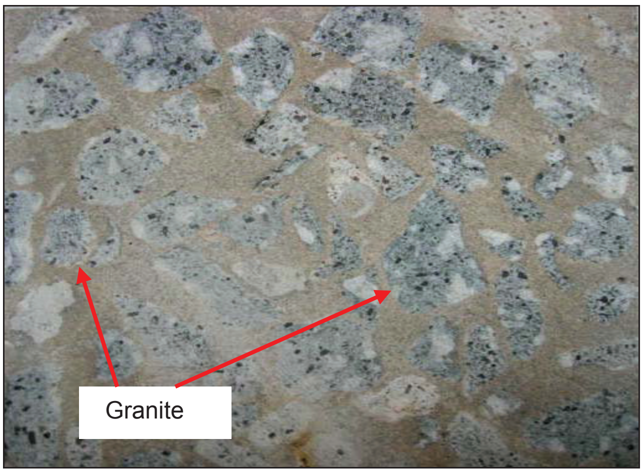

Figure 3. Insight of NWC

METHODOLOGY

To obtain a uniform concrete mix, the following mixing procedure was adopted. For OPS hybrid concrete, the crushed granite aggregates were first fed into the mixer, followed by the OPS (in SSD condition), the sand and cement. For the concrete in the rotating state, the components were mixed thoroughly prior to adding of the required amount of solution of water mixed with the required dosage of superplasticizer. The mixing was allowed for the duration of approximately 10 to 15 mins. In the process, the mixer was stopped so that any components adhering to the mixer blades or drum internal surface could be scrapped off into the mixture. The mix was then cast into the mould. Various sizes of reinforcement based on the length of C-channels were used.

Six prototype C-channels (Figure 4) were cast and cured for 7 days through water-spraying. With regards to durability, such curing duration was also recommended for concrete made with OPS aggregate (Teo, 2007). After which, due to space constraint in the laboratory, they were left exposed under the weather until the age of testing subjected to UDL up to deflection limit (i.e. span/250). It must be noted that precast concrete panels are usually cast under protected shade at the precast plants. Three companion 100 mm-sized cubes were also prepared to determine the 28-day compressive strength of the corresponding C-channels.

The UDL through a series of concrete blocks or cement bricks was applied on C-channels 3, 4, 5, 6, 7 and 8 m at the testing site. The blocks or bricks were arranged with gaps in between to avoid arch action. The schematic test and actual test setup is shown in Figures 5 and 6. Linear Variable Displacement Transducers (LVDTs) capable of measuring maximum displacements of 100 mm were positioned at midspan and at 300 mm from the end of span to determine the respective vertical deflections. The side of C-channels was white-brushed for crack detection.

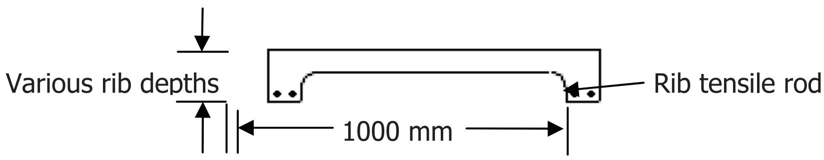

Figure 4. Cross sectional view of reinforced concrete C-channel

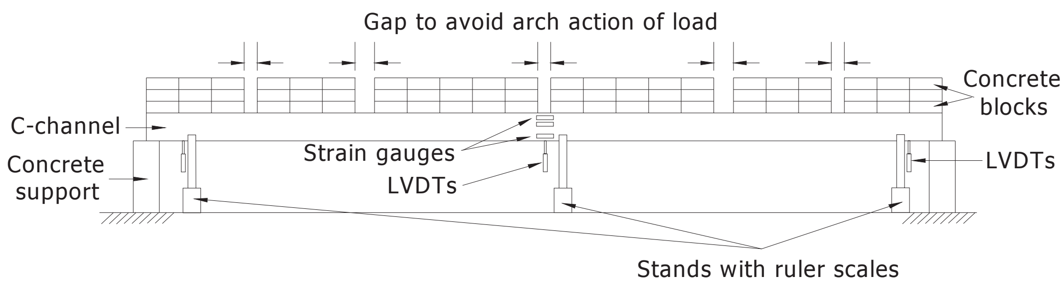

Figure 5. Testing setup subjected to uniform distributed loading

Figure 6. C-channel of 6 m span subjected to UDL up to deflection limit

Deflection recovery of C-channels was performed as per National Building Code of India (Part VI, Section 7). The loading duration was kept for one hour at its full span with a total load (including its own self-weight) of 1.25 times the sum of the dead and imposed loads used in design. For this investigation, the UDL was carried out on C-channels of 3, 4, 5, 6, 7, and 8 m span.

RESULTS AND DISCUSSIONS

As for C-channels tested with UDL up to deflection limit, the pattern of load-deflection relationship is shown in Figure 7. Based on BS 6399: Part 1, C-channel of 3 m span is designed for a live load of 1.5 kN/m^2 for residential purpose whereas all others of 4, 5, 6, 7 and 8 m span are designed for a live load of 3.0 kN/m^2 to account for the institutional or educational buildings. The corresponding load at deflection limits for C-channel of 3, 4, 5, 6, 7 and 8 m span was found to be approximately 18.04, 22.25, 18.16, 14.85, 14.00 and 12.98 kN/m^2 respectively. For C-channel of 4, 5, 6, 7 and 8 m span, it is clear to notice the corresponding load capacity reduced as the span increased. It is well understood that a structural element with longer span must have a greater depth so as to provide adequate strength. Also, the self-weight of the element is directly proportional to its depth and so the ratio of load carried to self-weight per unit length of the element is less favourable for larger span. According to Macdonald (2001), a structural member with shorter span subjected to UDL tends to have a reasonable capacity to carry additional load besides the bending moment generated by its self-weight. As the span increases, the bending moment generated by the self-weight would increase and consequently, an ever greater proportion of the strength available would have to carry the self-weight. Eventually a span would be reached in which all of the strength available is required to support only the self-weight. The structural efficiency to carry external load divided by its weight would steadily diminish as the span increases. Obviously, the longer the span, the greater is the need for high efficiency.

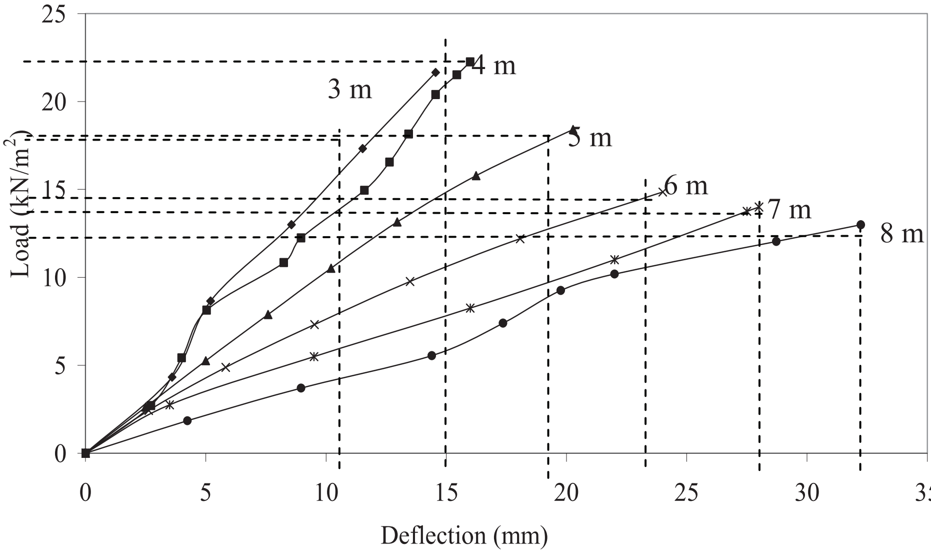

Figure 7. Load-deflection behaviours of C-channels of 3, 4, 5, 6, 7 and 8 m span loaded up to deflection limit (span/250)

As C-channels longer than 3 m span tested up to deflection limit and exhibited no evidence of failure, deflection recovery is further used as an evaluation criterion to determine whether the strength of the structure is satisfactory based on ACI 318-05. The 28-day compressive strength of the corresponding companion cubes was in the range of 22.15 to 23.58 MPa.

To further assess C-channels of 3, 4, 5, 6, 7 and 8 m span, their respective deflection recovery under a factored load was evaluated. It is noted that these C-channels were tested only up to deflection limit (i.e. 12, 16, 20, 24, 28 and 32 mm respectively for 3, 4, 5, 6, 7 and 8 m span), and that their structural behaviour at failure load remained unknown. It must be noted that total load applied up to deflection limit was higher than the total load required as per National Building Code of India (Part VI, Section 7). The deflection recovery of all spans of C-channels after one hour was between 87 to 98% which was more than 75% (Table 3).

Nevertheless, further investigation can be necessary to study the response of C-channels under failure load using uniform distributed loading. It must be noted that the ultimate behaviour of C-channel tested under two-line load until failure is very much similar to panel made with normal weight concrete (Ng, 2010).

The existence of cracks (Figure 8) induced by applied load affected the deflection recovery of C-channels as the degree of cracking affects the flexural stiffness. The flexural cracks developed during load increment affected the specimen recovery. The same observation was also reported by Izni et al. (2008) in investigating the precast prestressed hollow core slabs where the flexural cracks have caused a lower percentage recovery. For C-channels of 8 m span, shear cracks observed was the main factor reducing the recovery percentage below 90%.

Table 3. Deflection recovery (%) of C-channels of 3, 4, 5, 6, 7 and 8 m span

Panel						
Span, L (m)	3.0	4.0	5.0	6.0	7.0	8.0
Compressive strength of companion cubes (MPa)	23.40	23.07	23.58	23.04	22.66	22.15
Total nos. of flexural crack along full span	16	18	27	31	28	45
Occurrence of shear cracks	No	No	No	No	No	Yes
Total load required per Indian Standard (kN)	15.95	27.79	35.39	43.10	50.95	59.35
Total load applied at deflection limit (kN)	55.92	91.23	92.62	90.59	99.40	105.14
Deflection recovery after one hour (%)	98	90	92	93	96	87

Figure 8. Flexural cracks induced under UDL

CONCLUSIONS

A total of six prototype precast C-channel floors of 3, 4, 5, 6, 7, 8 m span were cast using OPS hybrid concrete. Based on this investigation on C-channel subjected to UDL, the following conclusion has been drawn.

1. Under UDL, the corresponding load capacity of C-channel of 4, 5, 6, 7 and 8 m span reduced as the span increased due to increasing self-weight which has to be carried.

2. The deflection recovery after one hour was found to be in the range of 87 to 98%, which satisfies the IS requirement. Nevertheless, shear cracks were found to influence the deflection recovery on C-channel of 8 m span.

3. This has proved that the C-channels of 3, 4, 5, 6, 7 and 8 m span can be fabricated using OPS hybrid concrete with minimum compressive strength of 22 MPa.

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RELATIONSHIPS AMONG SUPPLY CHAIN PARTICIPANTS IN DIFFERENT METHODS OF PROJECT PROCUREMENT

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Abstract
Supply Chain Management (SCM) is a concept that is used right across the world in many industries. SCM involves the management of relationships with all parties including client, contractor and sub-contractor in order to achieve the specific needs of a client's objectives in a project. Construction organisations that have an effective Supply Chain Management in place can expect reduced project costs and increased reliability and speed of facility construction. Several studies have been conducted over the past decade in establishing a preferred procurement method/process used on construction projects and defining the relationships that exist between each party involved in these projects, however, companies differ amongst one another which has resulted in an array of different responses. A short study was conducted last year to investigate above using both primary and secondary data collection in order to establish the extent of supply chain relationship and integration within Victorian construction organisations.

Keywords: *Supply Chain Management, Project Procurement, State of Victoria (Australia)*

INTRODUCTION

Successful construction relies on the contractor effectively bringing together a diverse range of trades and suppliers. The relationship formed from this task can sometimes be described as a temporary organisation in itself. Within this organisation, diverse and complex relationships are formed and integrated into a web of contractual agreements. Due to this bond, it is often very difficult to maintain a relationship without misunderstanding or miscommunication. Often relationships dissolve due to companies protecting their stake in this contractual web.

This paper discusses how relationships are maintained using real-life case studies. It examines the implementation of supply chain management and how it can be used to identify and resolve problems, create better relationships and the understanding between trades and suppliers of services for construction projects, depending on the specific project delivery method used.

The research of this topic was prompted because the practice of maintaining long-term relationships is not generally considered a priority in Australia. Therefore, the possible benefits of such relationships are not taken advantage of. The idea of documenting and maintaining subcontractor records was used as a basis for a questionnaire survey of five Australian building contractors and their direct subcontractors in the state of Victoria.

The aim of this short study was to compare our results and those prior researched internationally that generally show that contractors who are in a mode of recording relationship information with their subcontractors have mainly experienced indirect benefits such as effective communication, less conflict and reduced risk. In addition to this, some of the parties involved claim to have experienced lower costs or shorter times (Karim et al., 2006).

Karim et al. (2006) explain that most of the work in Australia is done by subcontractors as the main contractors rely on a large number of outsourcing of work. As much as 90 per cent of the construction work is carried out by a variety of subcontractors while the main contractor tends to focus on management and coordination. Furthermore, a large number of the subcontracting firms are small because the contractors tend to employ pyramid subcontracting by using multiple tiers of subcontractors. In Australia, for example, 94 per cent of construction trades employ fewer than five people, and less than 1 per cent employs more than 20 people (Commonwealth of Australia, 1999). As a consequence, most of these firms simply do not have the resources to adopt modern principles of quality management although their smaller size does provide them the flexibility to be able to adopt innovative methods. Further complications arise because the subcontractors are contractually obligated to the head contractor, whereas the construction process flows from one subcontractor to the other, as shown in Figure 1.

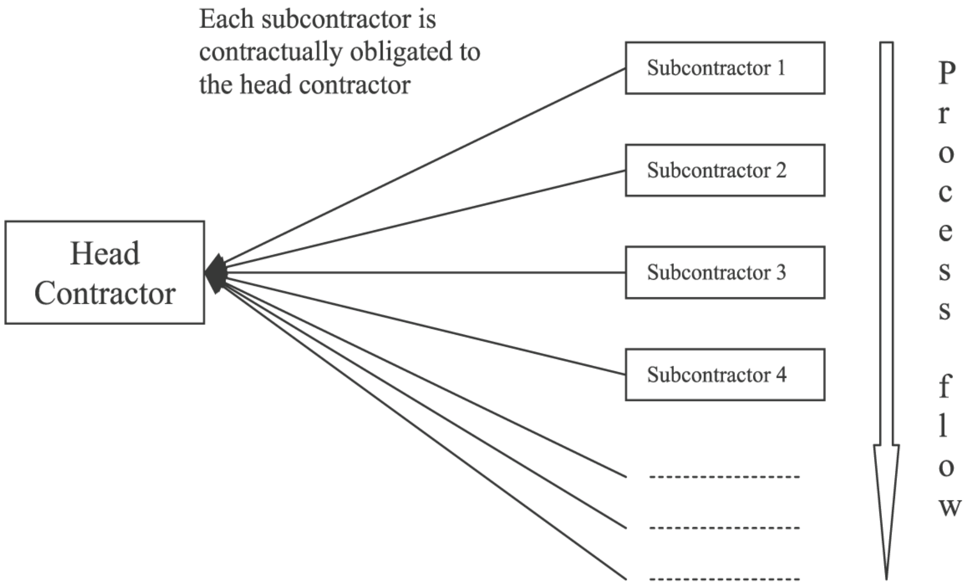

Figure 1. Conflict between contractual obligation and process flow

Combined with the fact that the main/head contractor has the final responsibility to deliver quality at a competitive price, make it essential for the main contractor to manage the supply chain effectively. Partnering approaches such as joint venturing have been introduced to overcome these problems. Although the construction industries implementation of these concepts has been far from rapid and is still in its early stages (Love et al., 2004).

The industry is made up of a complex set of relationships; large enterprises take on the role of project managers usually contracting or subcontracting to specialised and generally smaller enterprises for particular parts of the job. Each job brings with it a new configuration of relationships within the work site. In addition to this, the workplace itself is physically in a constant state of change. The changing workplace relationships and the pressure to review and update old work practices inevitably create new configurations of problems (Crowley et al., 2000).

SUPPLY CHAIN MANAGEMENT

Supply Chain Management (SCM) has emerged as one of the primary factors in determining competitiveness in today's construction industry. In recent times the construction industry has realised that competition is no longer dependent on the capabilities of individual organisations but on the ability of tightly integrated supply chains. Traditionally, clients/owners and contractors have generally seen each other as adversaries and in order to improve construction efficiencies, the need to develop relationships throughout the entire supply chain was evident.

Perspectives of Supply Chain Management

It is suggested that the construction industry has been slow in implementing or could be reluctant to exploit the concept of SCM (Love et al., 2000), in comparison to retail and manufacturing where they have been quick to realise that SCM has the benefits of maximising the business process in terms of efficiency and effectiveness through internal and external organisational relationships. In today's competitive construction industry, it is important that construction companies offer the 'best value' to their client and therefore, the need may arise to seek alternative suppliers and or subcontractors to perform the works.

To better understand the concept of SCM, Vollman et al. (1997) has suggested that construction SCM should be seen as an integrated framework to assist in managing and co-ordinating the chain from a project's conceptual idea to completion to its intended client. While there are many individuals in the construction industry that may claim to fully define SCM, there is no such definition that exists specifically related to construction; however Barker et al (2000) stated that SCM can be considered as *"the network of facilities and activities that provide customer an economic value to the functions of design development, contract management, service and material procurement, materials manufacture and delivery, and facilities management"*

The construction industry organisations have consequently realised that the utilisation of SCM in their organisation could be of great benefit. Barker et al suggests that if the construction industry is to move from an adversarial environment to one that is founded on collaboration then it should openly embrace SCM. It has been noted that SCM is a growing protocol as such that needs to be implemented into any project to ensure that the project is delivered within time and on budget and to assist in the relationship characteristics of the parties involved.

Procurement Selection

In determining the appropriate procurement method there is no 'better' method than others for an individual project, however no particular procurement method is likely to be better than others for any project (Love et al, 2000). According to Gordon (1994) he suggests that selecting an appropriate procurement method could reduce construction project costs by an average of 5%. However, while the selection of the procurement method may have this effect there are many subjective areas that need to be considered before making this judgement. Consequently, the selection of the 'better' procurement option is impracticable, as client and project characteristics differ constantly and the needs of each projects' characteristics will not be the same.

Links between Supply Chain Participants

Supply chain usually refers to the links between a client and contractor or contractor and subcontractor, which can be perceived as a buyer-supplier type relationship. The parties involved within a project some way or another are all involved in the supply of resources for that project, hence the supply chain. Understanding the role of SCM can be a hard process, however there are different areas within a supply chain process that distinguishes different levels of the chain. Giunipero and Brand (1996) define several levels of SCM including initial partnership (e.g. building good relations with suppliers and distributors), logistics management (e.g. implementing and controlling the flow involving all actors in the chain), and "genuine SCM" (e.g. continuous improvement of all aspects of the entire chain).

Influencing Factors

There are many influencing factors involved in construction when supply chain management is used and primary issues that often arise is between the client and head contractor. It is a complex decision to determine what type of procurement method would best deliver a project for differentiating clients. Every party involved in the relationship circle must be confident about what everyone's needs and wants are and most importantly to evaluate the client's criteria and objectives. SCM focuses on delivering a project by integrating all involved parties whereas Rowlinson (1999) states that conventional procurement selection criteria are based around the concepts of time, cost and quality.

Usually clients with many years experience within the construction industry are able to select a procurement approach that has worked for them before, or one that they know will be suited a particular project due to previous knowledge and experience in similar projects. However clients with less experience in the developing world need to seek advice from professionals who can set them in the right direction and assist them through the process and selecting the right delivery method.

The process in selecting the correct procurement method involves more than just establishing a contractual relationship between certain parties involved in a project, it involves a unique set of social relationships, which forms certain advantages within an alliance of competing interest groups. Conflicting goals and objectives of power within a project team are often the principal conditions for triggering adversarial relations (Love *et al*., 2004).

Supply Chain Management Implementation

The introduction of SCM in construction can be seen as a contributing factor to the revolutionising industry. The integration of SCM will also help promote and better perform procurement approaches that have been noticeable in the construction industry for many decades. The relationship between clients, consultants, contractors and subcontractors can integrate into SCM to better enhance the organisations efficiency and effectiveness. However, inevitable change and emergent means that different procurement methods have to be implemented to ensure that each project is delivered to the clients needs, this is evident as a number of alternative procurement approaches and forms of contracts have emerged since the 1960's in response to the changing needs of construction's more informed clients (Edum-Fortwe et al., 2001), and as a growing realisation route (Ball, 1988).

The initiation of the revolutionised procurement methods have been put into practice to further mitigate the impact on both the clients expectations and the delivery of projects on behalf of construction organisations. These alternative procurement methods, which include 'two-stage competitive tendering', Design and Build', 'Management Contracting' and 'Construction Management' represent some differences in relationships, roles and power between the design and cost consultants and main contractor, and between the main or managing contractor and the specialist and trade subcontractors. These added features or advancements give construction organisations flexibility in how the project is delivered and commissioned to clients. However, this may work against contractors where the procurement selection may favour a particular contractor over another.

SCM implementation varies according to the type of project and procurement process at hand. However, regardless of the difficulties associated with the procurement process selection, there are several methodologies, tools and models that have been developed and introduced into the construction industry to implement SCM and selecting an accurate procurement process. These approaches are becoming multifaceted and the range in selecting the correct procurement system is so great that it is actually becoming difficult to confidently choose a procurement method. For the purpose of overcoming this complexity, selection systems have been designed to be carried out in a closely controlled way within the framework of the clients overall project objectives (RICS, 2000).

There are many procurement selection methods when choosing to construct a project and clients are faced with the challenge for selecting the right procurement method. In order to determine how and why clients select a procurement method, a research has been conducted by Love et al (2008), which includes case studies and questionnaire surveys.

Factors Considered in Selecting a Procurement Method

An appropriate procurement method for a project will depend on several project characteristics including the factors that impact upon its delivery and desired risk allocation (New South Wales Department of Commerce 2006). This will provide value for money, manage risk and meet project objectives. As can be seen in Table 1 below, the characteristics of several Queensland (QLD) and Western Australian (WA) construction companies describe a number of selection criteria which was gathered by Love et al, 2008.
The information gathered above identifies the criteria of project value; project complexity, location, client factors and political considerations were identified by both sectors. However project time and cost risk profile, market forces were unique to QLD where as project type, stakeholder integration and industry culture were unique to WA.

The reason for these differences were due to QLD focusing on their procurement selection policy document and as a result it was found that the factors identified by the focus attendees in QLD are either driven or guided by this particular document therefore making a more structured process than those factors identified in WA. WA formed more of an implied process in choosing the correct procurement process for each project procured by the client.

Table 1. Company selection criteria (Love et al, 2008)

Queensland	Western Australia
Project time and cost risk profile; Project value; Project complexity; Market forces; Location (area/geography); Client knowledge, maturity and control; Refurbishment/new project; Political considerations; and Project quality.	Project value; Project complexity; Project type (standard/novelty); Location (regional/local); Stakeholder integration; Political considerations; Client needs; and Industry culture.

Process Used in Selecting a Procurement System

It was also found that traditional lump sum was the most commonly used by both states when delivering a project. The results showed that around 95% of projects delivered in WA, and around 90% of projects delivered in QLD, in the last decade have been procured using traditional lump sum. The findings also revealed that not only was this method the most common, but also the default option for both states. QLD also revealed that their working procedures are either driven or guided by their own in-house document. The Table 2 below outlines why traditional lump sum is popular in each state.

Supply Chain Integration

In order to stay competitive in the construction industry, innovation is the main characteristic that the organisation must possess. SCM can be seen as an example of evolutionary and cumulative innovation, which is often described as originating from internal programmes aimed at improving overall effectiveness. (New and Ramsay, 1997) Overall effectiveness is the key ingredient to managing the project to be delivered on time and within budget.

Table 2. Reasons for the popularity of Traditional Lump Sum (Love et al, 2008)

Queensland	Western Australia
Client expertise is not required; Project develops slowly; Ability to input into design and make changes; Political imperative; and Proven cost savings.	Policy; Ability to deal effectively with risk (cost, time, quality); Familiarity and acceptance within the local industry; Satisfies public accountability; Provides maximum client control over the project's outcome; and Provides cost certainty.

Greater effectiveness in a construction organisation not only allows smooth handover of projects but also allow the organisation to deliver a quality product reflecting on the organisation's mission and goals. Furthermore, it can be seen as a set of practices aimed at managing and co-ordinating the whole supply chain from raw material suppliers to end customers (Vollman et al., 1997) and which develop greater synergy through collaboration along the whole supply chain. Thus, the suppliers working with close relationship with the purchaser to maintain an effective work ethic in achieving the same objectives and form a sense of trust to repeat business in the future.

The significant emphasis on co-ordination and integration is strongly linked to the development of more effective and longer-term relationships between buyers and suppliers (Spekman et al., 1998; Koskela, 1999) allowing these new types of relationships to utilise resources more efficiently through the whole supply chain. Thus, closer relationships will, as mentioned build the trust and ensure that further works can be negotiated in terms of price and delivery times. In addition effective and efficient characteristics of the construction organisation can pass the savings on to the client through the supply chain, having achieved this relationship between the above-mentioned parties.

Although the integration of SCM can be a long and complex process it forms an imperative procedure in the way the organisation handles its resources to minimise waste and better performance standards in delivering the overall project. SCM can also be seen closely dependent upon the ability to create, manage and reshape relationships between individuals, organisations and networks within the supply chain (Spekman et al., 1998). This procedure demonstrates the shared responsibilities required from internal structures to external linkages and organisation processes to successfully deliver the required project.

Subcontractor Relationships

Disputes often arise due to poor planning and lack of coordination between the clients, contractors and subcontracts. To minimise disputes, the project team will need to ensure that all systems are put into place to overcome project deviation causing disputes to avoid delays and disruptions. Having said this, it is imperative that when disputes arise they are dealt with efficiently and effectively so they are minimised to avoid further costs. Thus if they are not attended to they could 'boil over' and mediation may be involved. In deriving the most productive remedies to reduce disagreements and to ensure the constant flow of works, traditional approach to project planning needs to be re-examined (Kosela, 1999). By re-examining the current practice of project planning, better two-way communication must be committed to, as well as pre-existent relationships.

The manner of which instructions are delivered and perceived may be interpreted differently and therefore consideration must be given when giving an instruction or informing people on what needs to be done. However, Ballard and Howell (1997) have suggested that "did" to "should" be implemented in conveying instructions, to avoid misunderstandings by persons involved and to assist in carrying out activities correctly. The increasing pressure of falling behind on a project and trying to gain back time is often the ideal catalyst for relationship breakdowns and therefore that commitment to SCM needs to be implemented to minimise impact. For this reason, establishing the work environment begins by acknowledging making and keeping commitments to what should be done and only to the extent that it can be done (Howell et al., 1993).

If contractors have previous relations with subcontractors and can manage to work closely with them then it enables the contractor to determine the resources required and the level of communication necessary in effectively portraying what need to be done and what is expected of the subcontractor (Ballard, 2000). Alternatively, if what should be done is rendered, then the site personnel may become accustomed to this type of relationship and automatically keep asking for direction in contract works. This can cause uncertainty and lack of production and can cause delay in works due to lack of initiation and bearing on behalf of the subcontractor.

Limitations and Implications of Supply Chain Management

Just like any implementation of a new system or framework system, limitations and implications are inevitable. Thus the proposed SCM model has taken a back foot in construction as such to integrating design and production processes. Such areas are in need of further development before SCM can be applied in a construction industry environment. Areas that are in need of further research and understanding include: The legal constraints and issues pertaining to the allocation of risk and accountability, specifically in the design aspect liability in construction projects need to be accounted for. According to Gaafar and Perry (1999) the extent of liability is not necessarily dependent on who is responsible for what, but rather who accepts the responsibility. Consequently further investigation is required to analyse the implications of adopting an updated contractual system proposed to interact with project SCM model.

There are issues surrounding the selection of project teams and in regard to public projects, it cannot be seen as advantaging only a selection of contractors. If the government body were to employ a SCM framework, then they are conflicted upon by public accountability and issues relating to integrity. This needs to be examined fully so that the framework is fair and readily available to all. Furthermore, a consultative process needs to be taken to be able to gain feedback on suitable implementation techniques for the construction industry. Due to the fact that there is insufficient information available to contractors regarding a SCM framework, this needs to be implemented and promoted in accordance with government policies and legislation.

The above presented literature review has briefly demonstrated that there is significant awareness of the importance of SCM and its main objectives to the construction industry. SCM may help construction overcome the 'fragmentation and adversarial culture, improve its relationships and better integrate its process' (Saad et al, 2002). Additionally, the construction industry has been comparatively slow to take off of this kind of management approach; this could be mainly due to an already well-organised and documented construction industry. Reviewing the results of the case studies, Khalfan and McDermott (2006) concludes that contractors are more oriented towards clients rather than their sub contractors and suppliers in the supply chain and would have more arrangements with their clients. It also argues that contractors have tendencies to pay more attention to clients who provide their workload.

However, SCM integration into an unfamiliar construction organisation without prior management systems, it could be difficult to adapt due to its diversity and understanding. This was found as Managers were hesitant or unwilling to rationalise their supplier and customer bases, to establish a clear common purpose and exchange information openly, which can be seen as reluctance to adopt Supply Chain Management relationships into their construction organisation. Aforementioned, another problem with implementing SCM within the construction industry at present is associated with an inappropriate established construction culture and the unique features of the organizational environment. Therefore, the objective of SCM is to create the most value, not only for the client and contractor but also for the whole supply chain network involved.

METHODOLOGY

The hypothesis of the research was to examine that the extent of relationships that exist amongst parties are not affected by changes to the way in which a project is delivered. In order to verify the above hypothesis, a generic questionnaire comprising of 16 qualitative questions and cover sheet was prepared by the researchers and sent out to selected twelve large first and second tier builders and subcontractors in the state of Victoria, Australia to conduct a pilot study. The questionnaire's main purpose was to collect insight into the different relationships that exist between contractual parties amongst different project delivery methods. Qualitative data was determined to be the most effective type of data collection for this research as it seeks to understand a given research problem from the perspectives of the participants it involves. The design of the questionnaire was carefully composed to address any missing gaps in the literature review and to test the hypothesis. The additional reasons for selecting this method of collecting data were; having ease of analysis, and effective when time is constraint.

DATA ANALYSIS

A summary of the questionnaire results has been compiled into a response matrix as shown in Table 3. The analysis of the results is further discussed and compared to the secondary data from the literature review in the following sections.

Analysis of Results

The primary responses acquired from the participants have provided a solid base to carry out the analysis achieved by the research objective. When comparing the answers to the questionnaire certain trends have been identified. It was found that a candidates path in the workplace i.e. diploma, degree or an apprenticeship has absolutely no bearing on their understanding of supply chain management in an Australian context. For example, when asked about the understanding of supply chain management in Australia, 7 out of 12 participants interviewed stated that the basic concepts of the terminology were understood in a general context but at the same time the majority of respondents leaned towards the view that it was not an effective management system in their experience for the nature of the Australian construction industry.

It is agreed that presently, there is no definitive answer to what an organisations most important procurement method is. All participants agreed that whether the delivery method is Lump Sum, Design and Construct, Construction Management, Alliance, or a PPP; they are all equally important in their own right and each presents a different perspective when it comes to working relationships. Likewise all the participants also agreed that project delivery is unique in every instance and certainly reflects on client – subcontractor – contractor relationship. Taking that into consideration when asked to specifically rate procurement methods from most important to least important, overall Lump Sum contracts stand out with 6 out of the 12 choosing this method. Furthermore it is clear that when comparing the results of Contractors and Subcontractor responses as a whole, it is evident that contractors have no particular preference but subcontractors clearly opt for a contract that has an aspect of price certainty and firm a responsibility strategy such as Lump Sum (see figure 2).

In order to achieve the objective of this research, i.e. to determine whether varying procurement methods impact or alter subcontractor - contractor relationships, we set out to establish whether the way in which a project is delivered reflects on the relationship between parties. As our initial prediction was that relationships are not affected by changes to the way in which a project is delivered. 11 out of 12 respondents answered that yes to a certain extent relationships are inevitably manipulated by the way in which a project is delivered.

Table 3. Questionnaire Response Matrix

Participant	Q3	Q5	Q6	Q7	Q9	Q10	Q11	Q12	Q13	Q14	Q16
1	Chief estimator	Degree	Not effective	Alliance	Yes	All	Continual	Direct exposure	Not worth focusing on	Definitely	Find common ground
2	OH&S Rep	Apprentice-Ship	Nil	CM	Yes	All	Not priority	Mediation	Yes	Both ways	Help out the situation
3	Site supervisor	Degree	None	D&C	Yes	All	Balance	Give and take	No	Both ways	Cease networking
4	Contract Administrator	Degree	None	Lump Sum	Yes	All	Balance	Cohesive resolution	No	No	Avoid ceasing contract
5	Contracts Manager	Degree	Turnkey Management	Lump Sum	Yes	All	Price	Settlement	No	Depends	Avoid
6	Contract Administrator	Degree	Contract Management	CM	Yes	All	Continual	Meetings/ Procedures	Not particularly	More disputes	Poor procurement methods

(a) Contractor comparison

Participant	Q3	Q5	Q6	Q7	Q9	Q10	Q11	Q12	Q13	Q14	Q16
7	Contract Administrator	Other	Relationships existing above and below	Lump Sum	Yes	All	Continual	Negotiation	No	Longer the more positive	Not occurred
8	Site Manager	Apprentice-Ship	Hierarchy of control	D&C	Yes	All	Priority	Find Resolution	No	More disputes	Avoid
9	Director	Diploma	No idea	CM	Yes	All	Never price	Face to face meetings	No	Both ways	Rectify situation
10	Project Supervisor	Apprentice-Ship	Control of items to produce product	Lump Sum	Yes	All	Balance	Admitting mistakes	No	Both ways	Avoid at all cost
11	Contract Administrator	Diploma	Supply and purchasing	Lump Sum	Yes	All	Price	Negotiation	No	Both ways	Networking will cease
12	Carpenter	Apprentice-Ship	None	Lump Sum	No	All	Balance	No effect on future relationships	Yes	Both ways	Not occurred

(b) Subcontractor comparison

One of the most important factors that need to be considered when a relationship is dissected is inevitably the price factor. Is lowest price the ultimate decider when tendering or do other issues come into play such as existing or prior relationships, quality of work, the project location, existing plant or past and present reputation and/or perception. A decisive 12 out of the 12 respondents agreed the lowest bid is crucial but more important is a balance of all of the above.

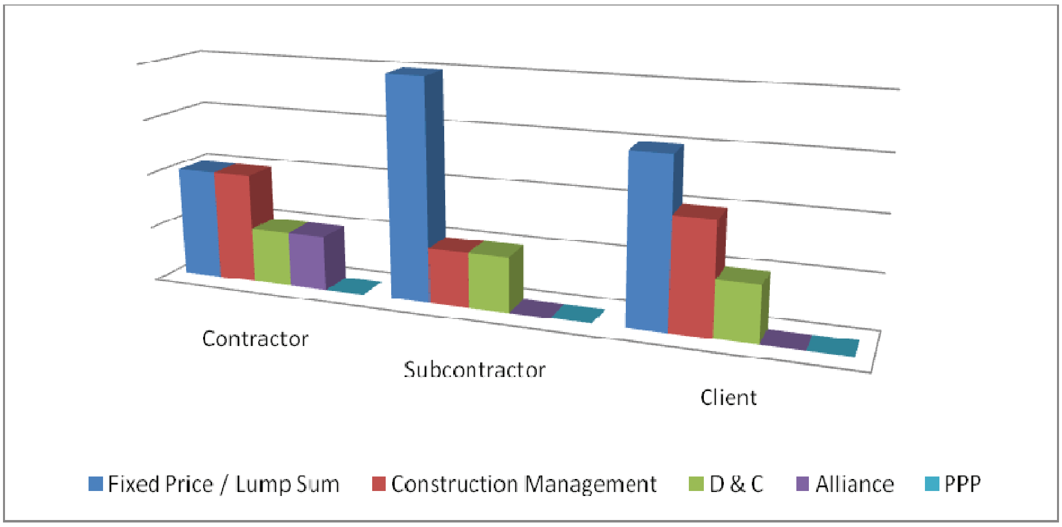

Figure 2. Procurement preferences of parties involved

Participants were further asked if continual work within existing relationships was a priority or is the decision simply price based. Only 1 of the 6 contractors and similarly 1 of 6 subcontractors stated that price is more important that continual work. The rest of the results were a mixture of the balance of both price and continual work (4 out of 12 respondents) and continual work being a priority (4 out of 12 respondents).

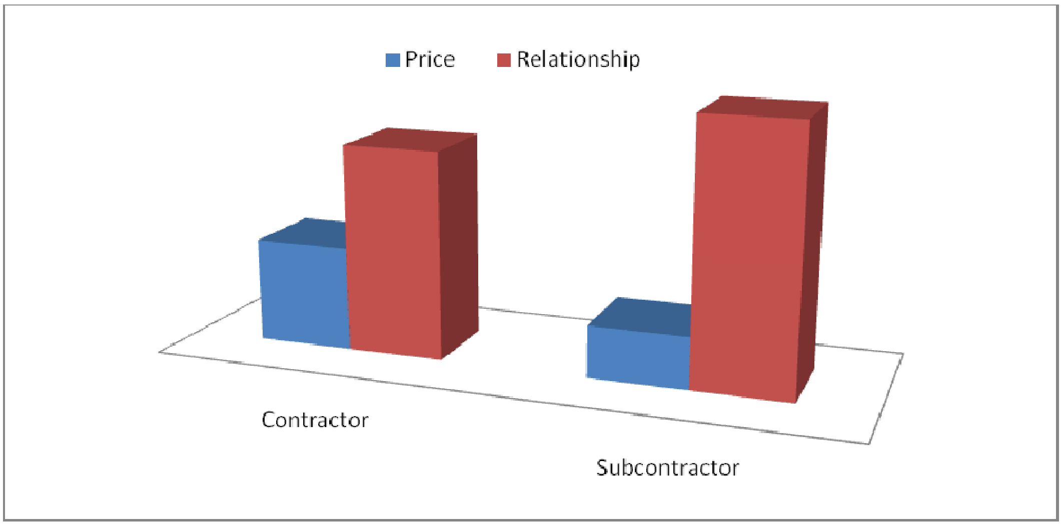

Figure 3. Price vs Relationship

One of the minor concerns of this research questions how disputes are resolved when differences occur and in turn how that affects future working relationships. Sufficient results have been gathered from the questionnaires to provide the answer to this question. When asked how to best resolve disputes, the majority of respondents replied with a form of negotiation, i.e. Mediation, Settlement and Meetings.

Furthermore it was found that results sufficiently demonstrate that both contractors and subcontractors agree that disputes are very common in the Australian construction industry and as long as they are resolved in a timely and costly manner, it shouldn't have little effect in terms of future relationships with either party.

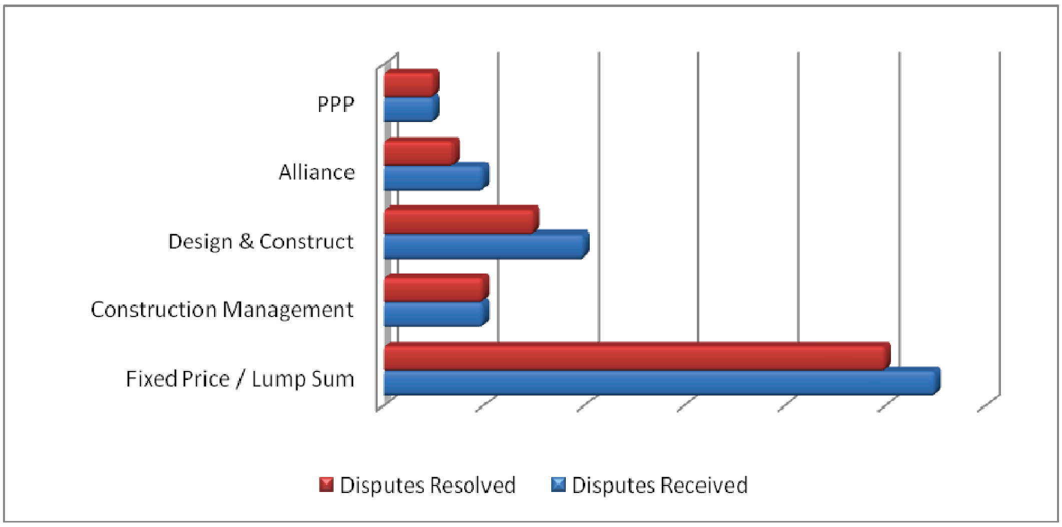

Figure 4. Dispute resolution relation

The findings also revealed that maintaining and reviewing company relationships with a strategic approach is one that receives little focus. Outstandingly the results reveal that 0 out of the 6 contractors and only 1 out of 6 subcontractors have a technical means whereby they monitor the health of relationships. It seems that several systems do exist for scoring subcontractors but as Participant-1 (Chief Estimator) explains 'it is not worth focusing on, simply because companies in our industry are constantly evolving'. The general idea that respondents gave is one of people moving around often, some companies go bust and some grow simply. Keeping in mind that a subcontractor reputation is very important but this is something that is gathered through tendering and experience, the industry evolves in the long run and therefore records are not worth dwelling on too much.

When asked if the duration of a project potentially allows for a closer bond between parties, a fairly mixed response is given. 2 of the 12 respondents agree that it definitely allows for a closer bond. On the other hand 7 of the 12 respondents are under the impression that it is just as likely that disputes will arise with longer projects as for a bond in relationships. Furthermore 3 of the 12 respondents say that extended duration on projects causes more disputes.

To get an overall opinion on the extent that projects have on relationships, a concluding question was asked to understand what the implications of contract termination are, and whether networking with the party will cease if this occurred. In a similar fashion to Question 12's responses – respondents main aim is avoid contract termination at all costs and get back to work as soon as possible and deal with problems in a manner that involves a bit of give and take. There is only one participant to recommend 'networking with the party to cease'.

CONCLUSION

It was found that relationships within the supply chain of construction are influenced by many contributing factors. It was revealed that contracting structures and styles significantly affect the relationships between organisations and that procurement techniques and contractor selection is an imperative process in keeping strong relationships for the duration of the project or contract works. Through Supply Chain Management the above can be incorporated into construction projects as a new method of project delivery. SCM is an emerging concept in the construction industry and this paper found that the participant in the industry has little to no understanding of SCM principles. It was noted however, that almost everyone interviewed within the industry acknowledge the concepts of SCM if portrayed in laymen terms. Also through extensive literature research, it was found that the majority of papers express SCM principles in one form or another. This paper found that the main difference between conventional procurement methods and SCM lays in the emphasis that is placed on incorporating relationships and collaboration between all project parties. It is crucial for organisations to move away from traditional procurement and project delivery methods to promote SCM framework in order to stay competitive in the ever changing industry environment.

This paper revealed that in order to implement SCM models then it will have to be initiated by the client in predominately public projects. This is because there is extensive policy and framework required in order to facilitate the total SCM model. However, experienced private clients should begin researching ways to prepare and hopefully integrate SCM prior to it being a necessity to compete on larger projects. For SCM to occur in Australia, it is necessary for industry leaders to be educated about the potential time and cost savings that could be acquired through implementing SCM models. It has shown in many studies that through education and training in unfamiliar areas of knowledge, it makes it easier to grasp new principles and concepts. Thus it will be required that industry leaders need to be proactive in the learning process of SCM in order to fully understand and appreciate the significant reduction in cost savings that can be achieved through SCM. It was noted in section two that clients may well invest these savings into other facilities and thus use the same project team to deliver their future projects. This in hand will create additional work for participating SCM users and will benefit the industry as a whole by increasing productivity.

In conclusion SCM will help secure stronger relationships and assist in keeping them constant throughout prescribed contract works. It will also ensure business connections are maintained and consequently provide more efficient project procurement and delivery systems. Ultimately, SCM should be introduced in the near future in the Australian construction industry to promote efficiency and increased cost savings.

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GUIDE TO AUTHORS

Aims and Scope:

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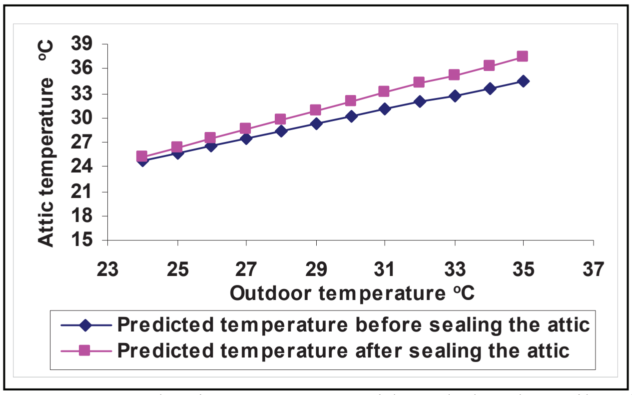

Figure 8. Computed attic temperature with sealed and ventilated attic

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Table 1. Recommended/Acceptable Physical water quality criteria

Parameter	Raw Water Quality	Drinking Water Quality
Total coliform (MPN/100ml)	500	0
Turbidity (NTU)	1000	5
Color (Hazen)	300	15
pH	5.5-9.0	6.5-9.0

(Source: Twort et al. 1985; MWA,1994)

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